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FEASIBILITY OF DEVULCANIZATION OF RUBBER FROM SCRAP TIRES

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FEASIBILITY OF DEVULCANIZATION OF RUBBER FROM SCRAP TIRES

Final Report No. 92-T21-58-11655 (Revision 2)

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Notes to the Reader

- *The original version of this report was submitted to the then Ministry of the Environment on December 15, 1992. This revised version contains only minor editorial changes and references to the present name of the Ministry to which it was submitted.*

- *Appendices D and E of this report have not been included in this version published by the Ontario Ministry of Environment and Energy.*

Copies of these appendices of the report are available by contacting:

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Abstract

The following report on the "Feasibility of Devulcanization of Rubber from Scrap Tires" was carried out by ORTECH International. The work was the result of an unsolicited proposal which was fully funded by the then Ontario Ministry of the Environment, Industrial Waste Diversion Program (IWDP). ORTECH would like to thank the Ministry for funding the first phase of this overall program

ORTECH International (formerly the Ontario Research Foundation) is a broadly based contract research, development and technical service organization with over 300 employees. As Canada's leading independent resource for problem solving and the development of ideas, ORTECH generates more than 75% of its professional service revenue through industrial clients. With its headquarters in Mississauga the organization serves the needs of over 2500 clients per year.

The Polymer Technologies Group at ORTECH comprises over 20 scientists, engineers and technologists who are involved in areas including Polymer Chemistry, Plastics Technology, Coatings, Adhesives and Industrial Design.

This project was conceived as the first phase of an overall program with the ultimate goal of selecting an appropriate devulcanization process, demonstrating its technical feasibility and eventually transferring the technology to industry. The work covered in this report includes a literature search on patents and literature regarding rubber reclamation (devulcanization), laboratory scale demonstration of two types of reclamation, a preliminary look at process and product economics and finally a review of potential applications. A more detailed summary of the work carried out can be found in the Executive Summary of this report.

The initial proposal and progress reports on this work were entitled, "Feasibility of Devulcanization of Rubber From Waste Tires". At the request of the ministry the final report was entitled "Feasibility of Devulcanization of Rubber from Scrap Tires", as the term *scrap* is more commonly used to describe waste tires. No other changes were made to the text.

Finally the authors would like to thank Irene Pater, P. Eng. of the Funding Programs Unit of the Waste Management Branch of the Ministry of Environment and Energy. As the Project Engineer responsible for coordinating the project on behalf of the ministry, her interest and assistance were invaluable.

Table of Contents

EXECUTIVE SUMMARY

Scrap tires represent a significant waste management problem. On the order of 10 million tires per year are generated in Ontario alone. In order to find a use for all of the scrap tires being generated a multifaceted approach will be required. One approach which is not being exploited in Ontario at this time is reclamation.

Rubber reclamation, or devulcanization, is a process which has been used historically, but has fallen into disuse recently. Reclamation involves devulcanizing the crosslinked (vulcanized) rubber to such an extent that it can be processed and subsequently revulcanized in another application.

A literature survey has identified a variety of reclamation processes which can be divided into two broad classes; Digester and Thermomechanical.

The feasibility of both of these processes has been demonstrated on a laboratory scale. Thermomechanical processes would appear to be more economically viable.

Preliminary cost estimates have shown thermomechanical reclamation to have the potential to be economically viable. Further definition of the required product properties and refinement of the process would be required to firm up the cost estimates. The fact that reclaim is being imported into Ontario and used in various products further supports the economic viability of reclamation.

Several companies associated with the rubber industry were interviewed and indicated that they did or would use reclaimed rubber in various applications if the cost-performance balance was acceptable.

The first phase of the project has been completed successfully and the technical objectives outlined in the proposal met. A phase II program would involve optimization of the reclamation process on a laboratory scale, evaluation of reclaim in selected applications and refinement of the process economics. Subsequent phases would involve pilot plant and then full scale plant production in conjunction with an appropriate industrial partner.

1. INTRODUCTION

In Ontario more than 10 million scrap tires are being generated annually. In the USA the EPA estimates that 2 to 3 billion scrap tires are stockpiled and that additional tires are entering the waste stream at a rate of 300 million per year. The scope of the scrap tire problem highlights the need to identify as many possible methods to recycle or reuse scrap tires.

The devulcanization, or reclamation, of rubber, specifically tire rubber, is a technology which had been practiced historically but had generally fallen into disuse. While some rubber reclamation may occur in captive plants the last major tire rubber recycling facility in Canada, Goodyear in Bowmanville, closed in 1985.

The overall objective of this project is to select an appropriate devulcanization process, demonstrate its technical feasibility and eventually transfer this technology to industry. The overall project is conceived as consisting of four phases:

- Selection of a process based on a literature survey, limited laboratory scale demonstration of the feasibility of the process, and preliminary evaluation of the economics of the process;

- Lab scale development of the process, optimization of process conditions, evaluation of various applications of devulcanized rubber, more detailed process and product economics;

- Design, construction and operation of a pilot plant operation;

- Design, construction and operation of a full scale plant.

The present work only covers the first phase. It is expected that the final two phases would be carried out in conjunction with an industrial partner wishing to commercialize the technology.

The purpose of the Phase I investigation was to provide documentation to support the technical viability of rubber reclamation, to demonstrate it by carrying out laboratory scale devulcanization, to carry out preliminary process and product economics and to identify potential applications. The overall goal of subsequent phases of this project would be to select, optimize and scale up the process for selected applications and to ultimately transfer the technology to an industrial user.

This report, the third and final, summarizes our finding on the 'Feasibility of Devulcanization of Rubber from Scrap Tires'. The work to be carried out was summarized in ORTECH Proposal #P.91.67-6539/OG(Revised). The work was divided into four tasks:

- Literature Review
- Laboratory Scale Demonstration
- Preliminary Process and Product Economics
- Potential Applications

The first two tasks were described in our reports PC91-58-11655-1 and 92-T21-11655-2, respectively, and were further elaborated in presentations to the then Ministry of the Environment on December 13, 1991 and July 23, 1992.

This report covers the final two tasks and, along with the previous two reports, completes the reporting of the contracted work.

The following two subsections summarize the Literature Review and Laboratory Scale Demonstration tasks of the project. For further details the reader is referred to the original reports PC91-58-11655-1 and 92-T21-11655-2 in Appendices D and E of this report respectively.

1.1 Literature Review

An extensive literature search was undertaken to review information on rubber reclamation technologies reported in the last 25 years. Electronic patent, technical and business databases and library holdings on rubber reclamation were reviewed. Over 100 books, articles and patents were reviewed in total.

The vulcanization of rubber involves crosslinking the rubber to yield the final product. A crosslinked rubber cannot be heated and reprocessed as with conventional thermoplastics. The process of breaking up the crosslinked rubber (devulcanizing) to the extent that it can be subsequently formed into a new product and revulcanized is called *rubber reclamation.*

The two processes which are more commonly used to recycle rubber at present are 1) rubber crumbing and 2) pyrolysis or incineration. In rubber crumbing the rubber is mechanically broken up into small particles which can be used as fillers in a variety of applications. In crumbing, the rubber is still crosslinked (vulcanized) but the reduced particle size allows one to process it. The crumb

must be bound together by another material to form a final product and as such acts essentially as a filler. In pyrolysis, the rubber is thermally reverted to recover simple organic chemicals which may ultimately be used as a fuel oil or in other applications.

The reclamation process has the potential to produce a higher value product than that from crumbing or pyrolysis.

Tire rubbers are mixtures of synthetic styrene-butadiene rubber (SBR) and natural rubber (NR) and various proprietary additives. In addition fiber and metal are added in the form of belts and beading. Historically as much as 10% of the rubber used in the production of new tires was reclaimed rubber. With the advent of high performance radial tires the demand for reclaim essentially vanished and the reclaim production declined.

Rubber reclamation (devulcanization) does not describe a single process or product. Reclamation is not an exact reversal of the vulcanization process and the properties (quality) required of the reclaim will be dependent on the intended application.

In general, the reclamation process can be broken down into three steps:

- Grinding;
- Devulcanization;
- Refining.

The scrap tire must first be ground into particles. The coarseness of the particles that will be acceptable will depend on the subsequent devulcanization process selected. Processes which are sensitive to metal fibre contaminants will require well ground rubbers which have had all of the metal removed. There is a significant and growing industrial capacity in scrap tire grinding.

Reclamation, or devulcanization, of the rubber can be carried out using a number of processes which fall into the broad categories of digestion and thermomechanical processes. In both cases heat and/or mechanical work are imparted to the sample in the presence of chemical additives. These processes will be reviewed in subsequent subsections.

After devulcanization the reclaimed rubber must still be compounded and refined to yield a product which is suitable for incorporation into its final application.

1.1.1 Reclamation by Digester Processes

Digester processes include the oldest methods for reclaiming rubbers. The processes include:

- Pan Process
- Steam-Air
- High Temperature Steam
- Wet Digester
- Novel Processes (see report 1)

Digester processes involve combining scrap rubber, reclaiming additives and water and heating the mixture under high pressure to around 200°C for several hours. A significant time is involved to allow the chemicals to diffuse through the sample and get a homogeneous devulcanization.

Advantages of the process include:

- less sensitive to metal contaminants;
- will accept larger particles;
- potentially high quality reclaim.

Disadvantages include:

- typically a batch process;
- long residence times;
- large waste water streams.

1.1.2 Reclamation by Thermomechanical Processes

Thermomechanical processes differ from digester processes in that the rubber is intensively mixed by a mechanical process. The temperature may be externally applied or a result of the mechanical shearing of the rubber. Lower levels of chemical additives are also typically required.

Advantages of the process include:

- typically a continuous process;
- short residence times;
- no liquid waste stream.

Disadvantages include:

- sensitive to metal contaminants and particle size
- proprietary details of equipment mixing configuration

The thermomechanical processes appear to have been more commonly used recently. The most serious disadvantage in developing a thermomechanical process is the lack of public information on the actual design of the equipment used and the exact operating conditions.

1.1.3 Environmental Considerations

While little information was available on the environmental considerations associated with rubber reclamation it would appear that wet digestion processes would raise the most serious concerns due to the generation of significant quantities of water borne wastes. The odor associated with both the process and the end product will be an issue for all types of reclaimed rubber.

1.2 Laboratory Scale Devulcanization

In that a variety of reclamation processes were identified, two approaches which represent extremes of the process were selected for laboratory evaluation. The processes selected were a conventional wet digestion for which literature formulation and conditions were available and a model thermomechanical process. Wet digestion was carried out in a pressurized stainless steel reactor. Since no details of the exact geometry of thermomechanical processing equipment was available a Betol BTS 40 mm twin screw extruder was selected. The thermomechanical reclaiming formulation was provided to us by a company which historically carried out rubber reclamation on the condition that the source not be identified.

Reclamation chemicals and crumb rubber were sourced commercially.

Four lots of rubber were reclaimed by a digester process with the details of the formulation and temperature varied between runs. Two thermomechanical runs were carried out with the residence time varied within each run and the control temperature varied between the two runs. The reclaimed rubber from all laboratory runs was compounded and cured (revulcanized) according to a rubber reclaiming standard method. The tensile and hardness properties were measured and hence revulcanization of the reclaim demonstrated.

In general the samples were found to show signs of inhomogeneous and/or incomplete devulcanization which resulted in cured samples which showed evidence of the crumb rubber particles which were reclaimed. This resulted in failure at the particle interface on the tensile measurements.

1.3 Process and Product Economics and Applications

The ultimate goal of the overall project is to demonstrate the technological feasibility of rubber devulcanization and to transfer the technology to industry. The final tasks for this first phase of the project involved preliminary costing of the preferred process and resulting product, followed by a tentative identification of potential applications and an identification of interest from potential industrial users of reclaim. The intent of the final two tasks was to provide a check that the rubber reclamation processes identified makes general financial sense and that there is likely to be some commercial interest in using reclaim should the project be extended to the next phase.

These two tasks have been reported in some detail in the following sections.

2. PRELIMINARY PROCESS AND PRODUCT ECONOMICS

2.1 Process Selection

Several requirements were used to assist in deciding which process, thermomechanical or digestion, was the best suited process for reclaiming rubber from tire scrap. These were:

- Product volume required;
- Final product properties;
- Operating characteristics of the process;
- By-products (i.e. disposal costs, toxicity);
- Specific advantages of each process being considered.

For the tire reclaiming process to be economical it has been estimated that production volumes should be approximately 1.0 - 1.5 million (MM) kilograms (kg) of reclaim per year. This estimate has been discussed with industry experts, including converters, end users and equipment manufacturers, all of whom consider this volume to be a reasonable estimate.

As described in ORTECH's progress report No. 92-T21-11655-2, the digester process requires a pressurized reactor (or series of reactors) to complete the devulcanization process. When production volumes, heating/cooling costs, the non-continuous nature of the process, unwanted effluents (digester water), lower physical properties and the slowness of the reaction (up to eight hours) are considered, the digester process would be the least desirable of the two manufacturing methods investigated. For this reason, only cost details pertaining to the thermomechanical process will be discussed in this review.

2.2 Materials Input

The materials required for the reclamation process can be broken down into two categories, rubber and chemicals. A discussion of materials sourcing and a rough costing will be included in the subsections that follow.

2.2.1 Crumb Rubber

The key feed stock in any rubber reclamation process is the crumb rubber. While all tire rubber is primarily a mixture of SBR and NR there are variations in the details of the proprietary formulations between each brand of tires. One issue which is not likely to be controllable is the exact composition of tire rubbers that is used. Any process that is selected must be robust enough to take whatever mix of tire rubbers is provided. This is further complicated by the fact that SBR and NR devulcanize at different rates themselves.

Crumb rubber is available from a variety of sources in North America. For the purposes of this work, the crumb used was sourced from Recovery Technologies in Mississauga, Ontario. This particular crumb is prepared by cryogenic grinding, a process in which the rubber is cooled to a glassy state and then ground. The product, as supplied, is essentially metal and fibre free. The price of the crumb is dependent on the particle size, with smaller particle size fractions costing more. The desired cleanliness (metal and fibre contaminant levels) of the product will also have an effect on the price. The price for truckload quantities of the crumb from Recovery Technologies for the various particle sizes is listed below:

Crumb Rubber Price , Recovery Technologies Inc., November 1992

Mesh Size	Price per kilogram
4-10	22¢
10-20	26¢
20-30	31¢
30-40	35¢
>40	53¢

These crumb prices compare to about $2.25/kg for virgin rubber. Lower quality rubber crumbs are available for 15¢/kg and lower. Since the overall goal of any reclaiming process will be to produce the lowest priced reclaim which has sufficient quality for the intended application, the cost of crumb will be a key factor. Other factors to consider will also be the security of supply and uniformity of the quality of the crumb.

2.2.2 Reclaiming Chemicals

The chemicals required for reclaiming will depend on the process selected. For the purposes of this report the thermomechanical reclaim formulation will be investigated in detail.

Bulk pricing on the chemicals that were used in the laboratory scale devulcanization are listed below:

Hipol, Petroleum Reclaiming Oil	:	25¢/kg
Heavy Aromatic Naphtha	:	50¢/kg
Peptrex Mixed Aryl Disulphides	:	$1.00/kg
Triethanolamine	:	$2.20/kg

As a rough approximation, the rubber reclaiming additives will cost about the same price per pound as the crumb rubber used in the process. The additive package used in the thermomechanical lab trial would therefore cost 44¢/kg.

Hence, since the crumb rubber will form the major component of the reclaim mixture (ca.85%wt), the cost of the crumb rubber will dominate the materials cost of reclaiming materials. Based on the numbers listed above the material costs for the laboratory thermomechanical formulation would be 37¢/kg.

2.3 Equipment

A full scale thermomechanical process is expected to consist of the same basic components used in the laboratory process.

For example, an appropriately sized compounding extruder will be used for devulcanization of the reclaimed rubber. A suitable feeder will be used to deliver the chemically impregnated crumb rubber to the throat opening of the extruder. The crumb will then be conveyed along the length of the barrel by the melt forwarding action of the screw, where the rubber will be reclaimed.

Inside the extruder the rubber crumb will be processed at a constant temperature, with heat being added or removed as required, by the heater bands and cooling channels respectively. As found in the laboratory testing, a residence time of 1.25 minutes is expected to achieve an adequate level of devulcanization. Once devulcanization has been completed the reclaimed rubber will have to be packaged in an appropriate form.

Final packaging of the devulcanized rubber will need to remain as flexible as possible so that the widest range of potential customers can be accommodated. For example, some customers may want the devulcanized rubber in bales (i.e. for use in virgin rubber blending), some in strips or sheets (i.e. for use in compression moulding) while still others may want pellet form (i.e. thermoplastic blending and injection moulding applications).

A preliminary block diagram of the process is illustrated in Figure 1.

2.3.1 Capital Cost Calculations

Before going into the actual capital cost calculation it is important to point out that the details of the thermomechanical process selected will dominate the cost of the process. Parameters such as residence time required, hence throughput, and capital equipment costs are based on an extension of the laboratory process developed. In the proposed second phase of this project, the process would be optimized and these parameters further refined.

In addition, the costs described in this report are based on acquiring new equipment as opposed to second hand and with a prime industrial real estate site being used.

The focus of the capital cost calculations will be on the extrusion equipment requirements. Facilities, auxiliary equipment such as storage silos, grinders and packaging equipment, have been treated less rigorously. Several cost scenarios have been prepared for review to show how key costs like hydro, water, building overhead, and wages, can effect the final product costs.

Please note all scenarios highlighted reflect costs which would be expected in the metro Toronto area. Plant location, local utility costs and ultimate operating efficiencies will cause predictions to change. Note that no provisions have been made for any applicable manufacturing taxes and related operating fees.

Assumptions made for each scenario are listed in Table I. A detailed description on only Scenario 1 will be provided in this report. However, results from all three potential cost situations have been summarized in Tables III and IV.

2.3.1.1 Calculation of Extruder Size Requirements

Example - Scenario #1

For the first prediction, a production volume of 1,500,000 kilograms per year was used. Allowing for statutory holidays, vacations and downtime (scheduled and unscheduled) approximately 46 weeks is expected to be available for production. Excluding weekends, this translates into 5,520 (i.e. 46 weeks x 5 days/week x 24 hr/day) hours of potential production time available to produce 1.5 MM kg of material.

This means the extruder would have to generate approximately 272 kg/hr (i.e. 1,500,00 kg/yr ÷ 5,520 hr) if it runs at 100% efficiency. However, it would be unreasonable to assume the plant would operate at 100% efficiency. Being conservative, an operating efficiency of 80% will be used. Extruder output output would then rise to 340 kg/hr (i.e. 272 kg/hr ÷ 0.80).

This value of 340 kg/yr also presumes that all product produced will be prime material. Once again, it would be more reasonable to expect that only 80% of the output would be acceptable. Using a utilization value of 80% the output of the extruder required would need to increase to a minimum of 425 kg/hr (i.e. 340 kg/hr ÷ 0.80).

One other constraint on the process is the estimated residence time of 1.25 - 1.50 minutes necessary for devulcanization to occur. Residence time is controlled by the length of the barrel and extruder speed (i.e. RPM). In order to get the necessary residence time the output of the extruder, in RPM, will need be slowed down to about 75% of capacity or approximately 570 kg/hr (i.e. 425 kg/hr ÷ 0.75). This estimated output of about of 570 kg/hr translates into an extruder having a screw diameter of about 80-85 mm (i.e. An extruder with this diameter is capable of 650 - 750 kg/hr) depending on manufacturer.

The relationship between residence time and RPM to determine barrel length can be described by Formula 2.3.1-1.

$$T = \frac{2 \times L}{N \times P} \qquad (2.3.1\text{-}1)$$

Where
T = Residence Time
L = Barrel Length
N = Screw speed (i.e. RPM)
$P = \dfrac{D}{SP_m} = \dfrac{85}{3.33} = 25.5$
D = Screw Diameter
SP_m = Screw pitch in metering section

Therefore
$$L = \frac{T \times N \times 25.5}{2}$$

$$= \frac{1.5 \times 200 \times 25.5}{2}$$

= 3187 mm in length

= 37:1 Length/Diameter

2.3.1.2 Extruder Costs

Quotations for an extruder with at least an 80 mm screw diameter and an L/D ratio of at least 37:1 were requested from two manufacturers, Betol Machinery Limited and Berstorff Corporation. Additional details about each manufacturer can be found in Appendix A and B. Cost details for each extruder have been provided in Table II.

2.3.1.3 Capital Depreciation

Using the budgetary figures from Table II and a straight line depreciation over 5 years, the yearly capital operating costs for an 80 mm diameter screw would then be roughly $260,000/year (i.e. $1.3 MM ÷ 5 yrs) or about $47/hr (i.e. $260,000/yr ÷ 5,520 hr/yr).

2.3.1.4 Power Consumption

Approximately 0.2 kwh of energy would be consumed per kilogram of material produced as specified by Betol Machinery. Using the value of 10¢/kwh as an estimate of local hydro rates and an extruder output of 550 kg/hr, power costs would be $11/hr (i.e. 0.2 kwh/kg x $0.1/kwh x 550 kg/hr).

2.3.1.5 Water (Heat Exchange Only)

The extruder requires approximately 50 gallons of water per hour for cooling purposes. At a water cost of about 0.3¢/gallon, this works out to be $0.15/hr (i.e. 0.3¢/gal x. 50 gal/hr x 0.01 dollars/¢).

2.3.1.6 Building Overhead

In the metropolitan Toronto area floor space costs have been found to range between $5-10/sq ft depending on location. For Scenario #1 a value of $10/sq ft. was used. About 4000 sq ft, for both office and manufacturing would be considered sufficient space for start-up of one line. Therefore, about $3500/month rent (i.e. ($10/sq ft x 4000 sq ft) ÷ 12 months) would be necessary. Converting this figure to $/hr, building overhead would add approximately $7.30/hr (i.e. $3,500/month ÷ 480 hr/month) to the operating budget.

2.3.1.7 Salaries

It is anticipated that to safely operate the extrusion line three process operators per shift will be necessary. One operator will be responsible for actual operation of the extruder (i.e. insuring operating conditions are maintained, general maintenance, appropriate equipment repairs, etc.) and monitoring process conditions. The second process operator would insure auxiliary (both upstream and downstream operations) equipment are functioning normally (i.e. initial raw material preparation, material packaging, etc.). A third operator would act as an assistant to the other two operators as they required and would be responsible for shipping and receiving duties, housekeeping and general maintenance.

In addition, three other people will be required to take care of general office duties. Two of these people will take care of general administration duties such as typing, accounting, sales inquiries, etc. The third person will be required as a general manager of the plant and would oversee the day to day operation of the facility.

Assuming an average wage of $17/hr for plant and office personnel and $25/hr for the general manager, a combined hourly expense of about $75/hr would be required. These figures take into account the difference between hours worked by office personnel and the process operators.

Overall budgetary figures established from the above calculations for all three scenarios have been summarized in Table III.

2.4 Output

Looking at the above budgetary estimate of approximately $140 per hour for initial operating costs for Scenario #1, this would translates into a minimum

asking price of about 26¢ per kilogram (i.e. $140/hr ÷ 550 kg/hour) of devulcanized rubber produced, excluding raw material costs. Adding the raw material costs of 37¢/kg (see section 2.2) the minimum asking price would be approximately 63¢/kg.

To make this venture attractive for an investor returns on the money invested would likely need to range between 10 and 20 percent. Considering this assumption the asking price for devulcanized material would need to be at least 70¢/kg. Results from all costing scenarios has been summarized in Table IV.

2.5 Summary

The current market price for reclaimed (devulcanized) rubber imported into Ontario from off shore has been reported by one source to be as much as 50¢/kg. The price can vary significantly and will of course depend on the quality required.

The rough costing carried out in this section suggests that the production cost of reclaim would be above the 50¢/kg quoted by industry. However the costing carried out makes several assumptions which may have inflated the cost of the reclaim. These include:

- use of a high quality rubber crumb;
- new capital equipment purchased instead of used;
- prime Toronto area real estate selected;
- generous labor rates.

Further refinement of the costing is not practical at the present time. It would, however, appear that the rubber reclaiming process could be carried out in Ontario at a competitive cost based on these initial calculations.

3. POTENTIAL APPLICATIONS

A key element in ultimately commercializing a scrap tire rubber reclamation process will be finding users who would commit to using the reclaimed rubber. This will of course be dependant on identifying applications and tailoring the reclaim to suit these applications. Our initial investigations indicate that there are users willing to use reclaim at the present time.

3.1 Industrial Contacts

To gauge the interest in reclaimed rubber, selected rubber converters and end users were contacted and interviewed in person. During each interview a number of questions were asked. The types of questions asked have been summarized in Appendix C. All of the companies contacted requested anonymity to prevent competitors from gaining insight into their operations and cost structures. For the purpose of this report the manufacturers will be identified generically and details of their operation that were covered in the interview will not be given. The companies interviewed included;

- a rubber convertor and recycler supplying to various automotive, commercial and industrial applications;
- a rubber compounder suppling to convertors for high end industrial applications including belts and hoses;
- a coatings and adhesives supplier producing rubber and asphalt based products for the construction and other industries;
- a multimaterials recycler with expertise in crumb rubber applications.

The following two subsections will summarize the discussion with these potential reclaimed rubber users and highlight issues associated with reclaimed rubber.

3.2 General Requirements for Reclaim

The reclaim used by the interviewed companies is being supplied from the US, Europe and the Far East. It was made clear in all interviews that there was a market for reclaimed (devulcanized) rubber if the price and physical properties were appropriate. What is acceptable reclaim will, of course, vary according to end use. The fact that reclaim is presently be used by several of the companies interviewed shows that reclaim with the appropriate price and properties can and is being produced.

Another key criteria identified is that the reclaim should not have any objectionable odour as a finished product. In ORTECH's initial evaluation program the reclaim rubber was found to emit a somewhat objectionable odour. This was commented on by at least two of the organizations we discussed this program with. This problem will need to be addressed prior to introducing this technology on a commercial basis.

Widespread used of reclaimed rubber in the Ontario market has been hampered by several stumbling blocks. The most significant problem is the poor availability of quality reclaimed material. Users have reported that reclaim is not readily available and that getting the quantity required with a reasonable delivery is frequently a problem. In other words, consumers of reclaim material have had to take what they can get when they can get it.

Some reclaim users have reported to us that they found it much less difficult to work with than they originally anticipated and have no reservations about using

this type of material in the future. Initial experience with these materials has been favorable, suggesting that an appropriately sized Ontario based producer might be well placed to displace imports and supply new markets. One of the advantages an Ontario producer would have is that they could work closely with their customers and develop a reclaim for an application in conjunction with one another.

Based on information given to us from industry contacts the physical properties of the blends produced at ORTECH as part of the specified laboratory trials, were also found to be comparable to, although some what lower than, materials presently available (and being used). A comparison of the physical properties of the commercially available material and product made as part of this investigation have been summarized in Table 5.

It should be noted that the ORTECH samples were not optimized materials and the properties could likely be improved. In addition, the desired properties of the reclaimed rubber will be dependant on the specific application the material will be used in.

Ultimately the key to the successful commercialization of a reclaimed rubber is its cost/performance ratio. All potential users of a reclaimed product will only use it if the cost of reclaim is considerably less than virgin rubber costs and the properties of the product they make meets minimum performance requirements.

3.3 Specific Applications

Discussions with industry have made it very clear that many applications being considered for reclaim would involve blending the reclaim with virgin rubber. The percentage of reclaim which would be used depends on the application but a range between 10-50 % would be typical.

One industry source has estimated his potential consumption of reclaim for existing production could easily be 1 MM kg/yr if sufficient quantity and quality of reclaim was available. Products manufactured which could include significant quantities of reclaim include sound barriers, flooring, mud flaps, truck bed liners, hoses and belts for use in both OEM and after market automotive applications.

Another company identified a number of applications, the largest of which was low speed tires for fork lift trucks and other similar vehicles. The company estimated that this was a 15 MM kg/yr market, 30% of the virgin compound could be replaced with a reclaim rubber. Hence this potential market could consume another 3 MM kg/yr of reclaim.

Another company with an application for reclaim was identified in the construction industry. Presently a very expensive virgin SBR rubber must be used in an asphalt product to obtain the proper consistency and rubberyness. The company indicated that it had used reclaimed rubber in this application previously but that it was no longer able to source the material and was forced to use the expensive virgin rubber. ORTECH's reclaimed material was tried in this application but was not sufficiently devulcanized for this application. However, this organization has expressed an interest in pursuing this option based on the economic benefits of using a reclaimed rubber versus a virgin SBR compound. If and when a reclaim rubber is developed to replace the SBR material another 2-3 MM kg/yr of material would be consumed in this application.

Another company which uses crumb rubber in a variety of applications indicated that it recognized the potential for substituting reclaim for crumb to yield higher value products and to reduce the cost of the resin used to bind the crumb rubber. Applications were identified for both straight reclaim and reclaim blends. This company estimated a volume of 1.5 MM kg/year would be a reasonable volume for their applications.

4. CONCLUSIONS

- Vulcanized rubber, specifically scrap tires, can and have been shown in the literature to be reclaimable;

- Reclamation of scrap tire crumb has been shown to be technically feasible on a laboratory scale by both digestion and thermomechanical processes;

- Thermomechanical reclamation appears to be the most environmentally and financially sound process investigated;

- An undesirable odour was generated during devulcanization of the rubber crumb. This odour persisted in the end product. Reclaims are available with significantly lower odors suggesting that the problem is surmountable;

- Initial estimates indicate that a scrap tire reclaiming facility in Ontario could be economically feasible and could produce a marketable product;

- Crumb rubber and capital equipment costs will need to be reviewed and optimized in the next phases of this work;

- Further optimization of the thermomechanical reclamation process would be required including tailoring the product properties to specific applications;

- Reclaimed rubber is being used in Ontario and there is no domestic supplier. If there was a larger supply there are additional markets for the product;

- There are a variety of potential applications for reclaim and several companies representing different market sectors have expressed an interest and/or indicated that they already use reclaimed rubber;

- The controlling factor for the use of reclaim will be producing a product which has the appropriate balance of cost and performance for the intended application.

5. RECOMMENDATIONS

- Details of the configurations of previous thermomechanical equipment should be further investigated;
- Alternate process equipment configurations including single screw extruders and continuous mixers should be investigated to determine if a less costly (or more effective) piece of reclaiming equipment can be identified for reclaiming crumb rubber;
- Continue refinement of the thermomechanical devulcanization process to improve physical properties;
- Investigate ways of minimizing the odour associated with reclaiming rubber using the thermomechanical process;
- Identify less expensive sources of scrap rubber tire crumb.

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Table I
Basic Assumptions For All Scenarios

	SCENARIO #1	SCENARIO #2	SCENARIO #3
Output (kg/yr)	1,500,000	1,500,000	900,000
Operating hours (hr/day, days a week)	24,5	24,7	24,7
Operating Weeks (per year)	46	48	48
Power (¢/kwh)	10	8	8
Water: (¢/gal)	3	3	3
Rent: ($/sq ft/month)	10	10	8
Wages: ($/hr/person (avg))	15	15	15

Table II

Extruder Cost Details (in Canadian Dollars)

ITEM	Betol	Berstroff	Average
Extruder			
80-85 mm diameter	575,000	550,000	562,500
60-65 mm diameter	320,000	400,000	360,000
Feeder	45,000	n/a	45,000
Product Handling			
2 roll Calendar			125,000
Miscellaneous Equipment (i.e. fork truck, tools, spare parts, storage bins, etc)			300,000
Extruder Installation (i.e. Electrical, mechanical, plumbing, etc.)			15,000
Contingency			250,000
			============
Capital Costs for 80 mm screw diameter			**$1,297,500**
Capital Costs for 60 mm screw diameter			**$1,095,000**

Table III
Operating Budgetary Figures

ITEM	Cost/Hour Scenario #1 ($)	Cost/Hour Scenario #2 ($)	Cost/Hour Scenario #3 ($)
Depreciation	47.00	45.45	35.00
Power	11.00	11.00	11.00
Water	0.15	0.15	0.15
Building Overhead	7.30	3.70	3.70
Salaries	75.00	65.00	65.00
	=======	=======	=======
Totals	**$140.45**	**$125.30**	**$114.85**

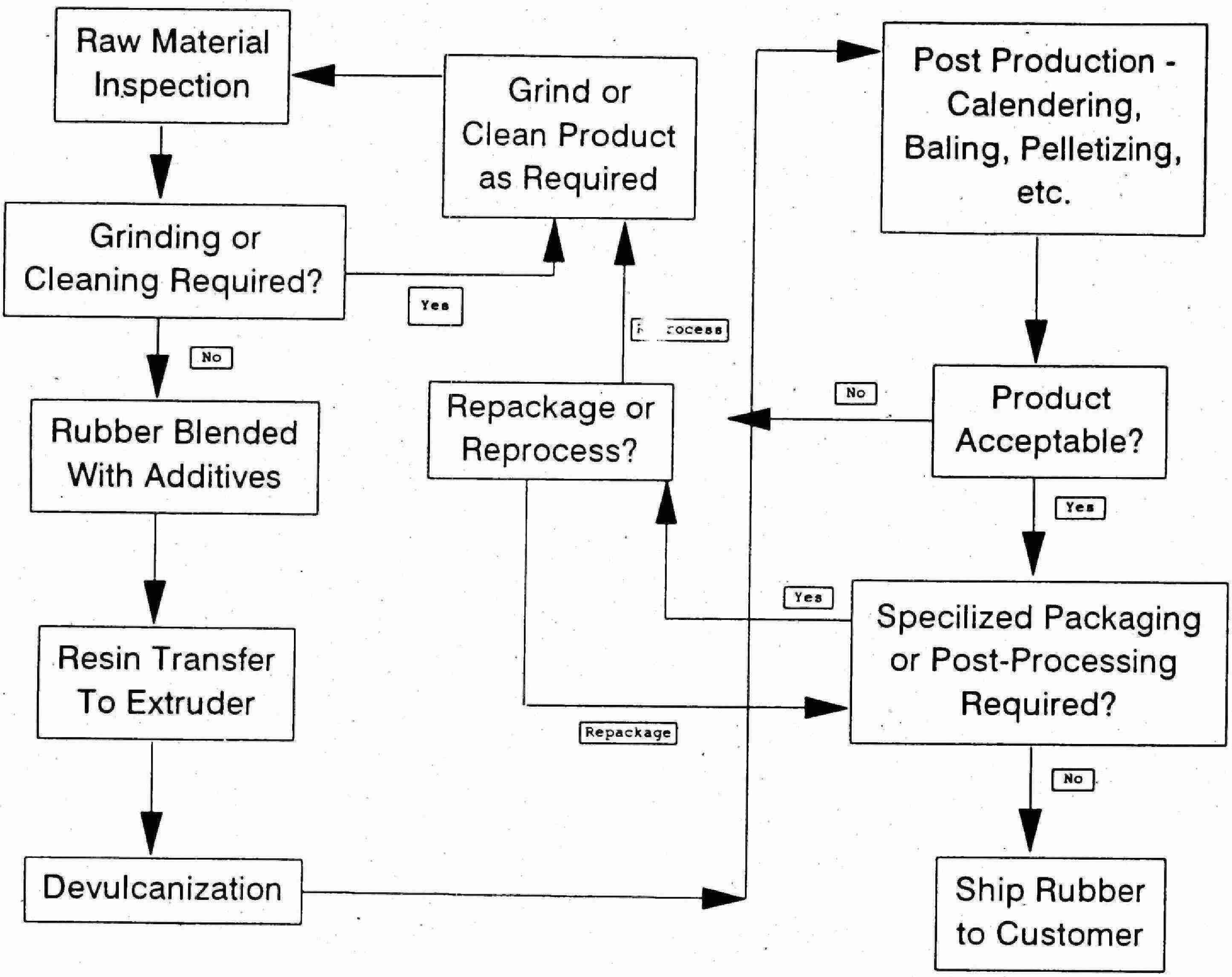
Table IV
Potential Costs for 1 Kg of Devulcanized Rubber (in ¢/kg)

Parameter	Scenario #1	Scenario #2	Scenario #3
Devulcanization	26.0	23.0	41.7
Raw Materials	37.0	37.0	37.0
Estimated Asking Price			
If 10% Return	70.0	66.0	86.7
If 20% Return	76.0	72.0	94.4

Table V
Comparison of Physical Properties of Commercial versus Laboratory Produced Reclaimed Rubber

Physical Property	US	Off-Shore	ORTECH
Hardness (Shore A)	55	60	55
Tensile Strength (MPa)	6	11	4.3
Elongation (Percent)	240	240	185

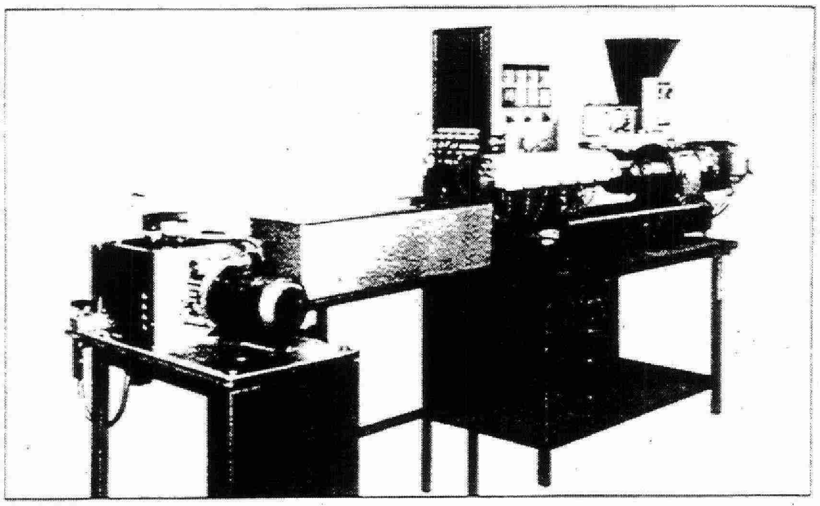
Figure 1 - Devulcanization Process Block Diagram



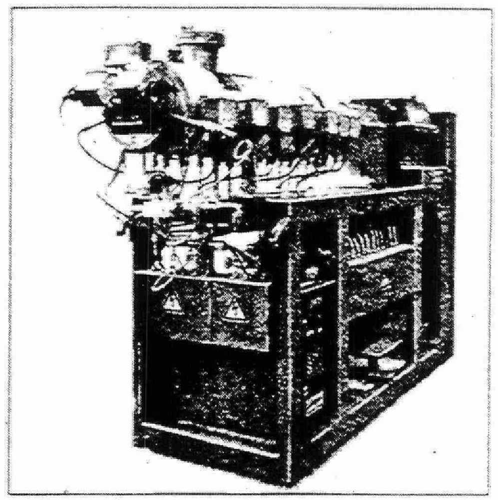
Appendix A

Extruder Manufacturers Information : Berstorff Corporation

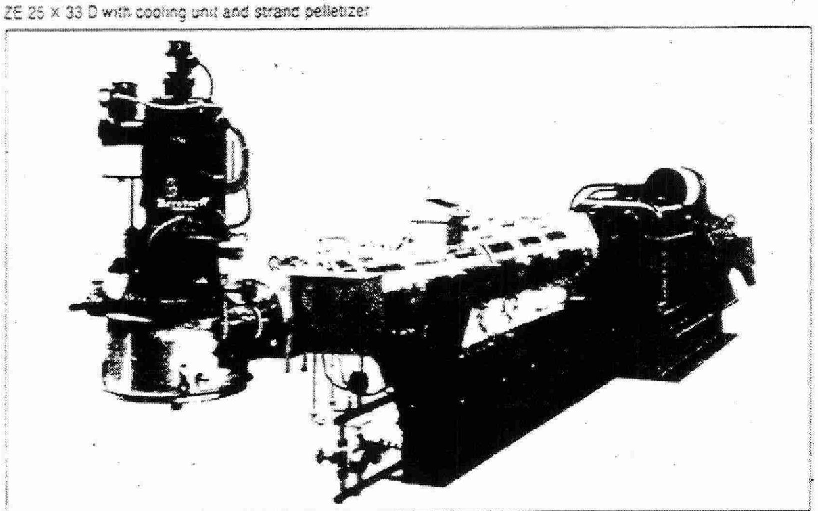
(23 pages)



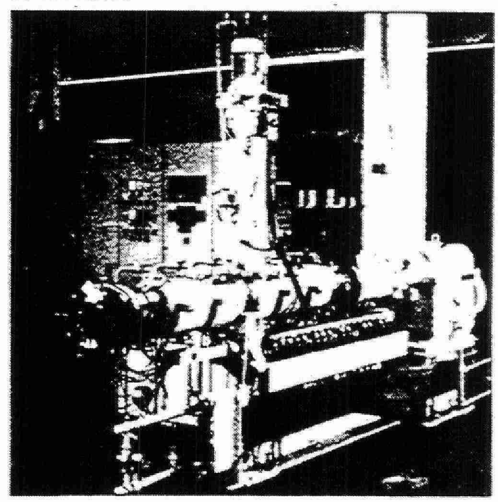
ZE 25 × 33 D with cooling unit and strand pelletizer



ZE 40 A × 29,5 D

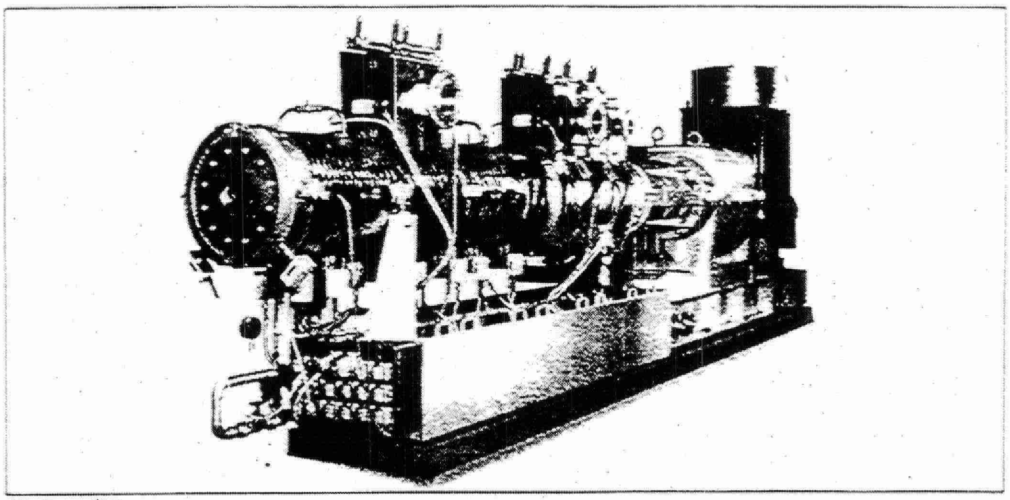


ZE 90 × 33 D with screen changing equipment and water-ring pelletizer

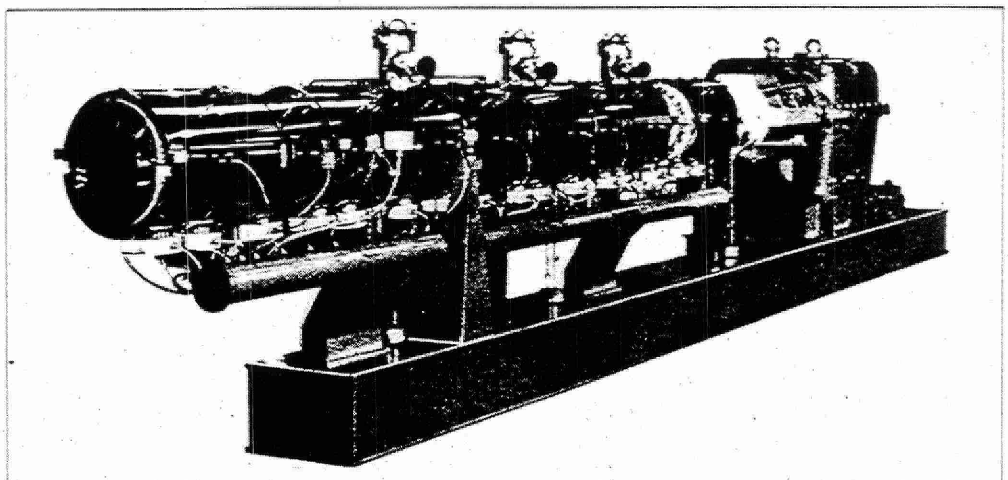


ZE 60 A × 33 D

Contents



ZE 130 A x 30 D



ZE 130/130 A x 10.5/32.5 D

Berstorff today: More than 80 years of experience in the development and manufacture of extruders

Today, Berstorff look back on several decades of experience in developing and manufacturing extruders, supplied world-wide not only to the rubber and plastics industry, but also to the paper, cardboard, cellulose, food and luxury goods industries.

With a total of more than 150 various types of extruders, from 25 to 650 mm screw diameter, Berstorff offer the most versatile extruder programme currently on the world market.

One of the milestones in the field of extruder technology, design and manufacture, is the world's largest extruder that was built by Berstorff in 1977. The screw diameter of this extruder is 600 mm and its length 26 D.

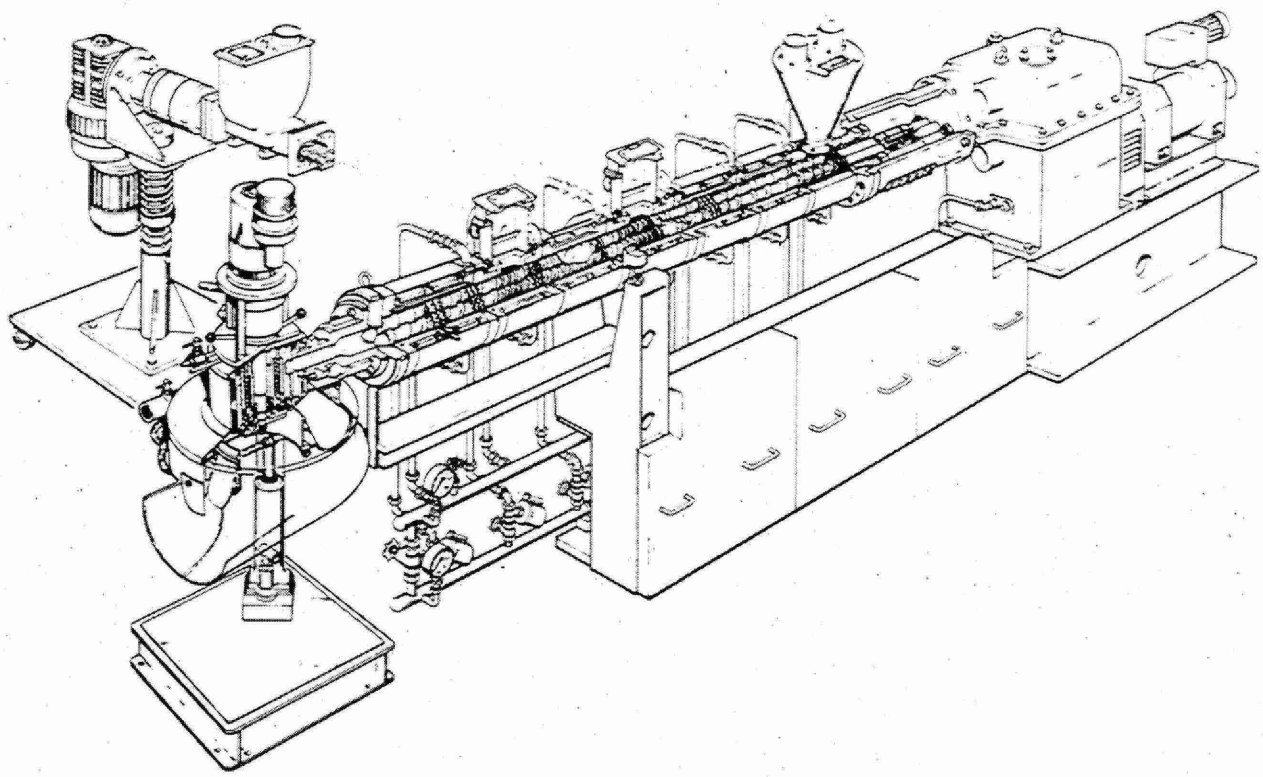
In order to select the most economic type of extruder for each individual process requirement, Berstorff supply single-screw, twin-screw, planetary gear and special extruders. This programme is supplemented by numerous auxiliary accessories and line equipment — such as pelletizers, screen changers, continuous melt filters, cooling units and pellets drying systems.

The first twin-screw extruder was built by Berstorff in 1966. The main engineering features, such as co-rotating and intermeshing screws were already integrated in this extruder at that time. Intensive research and development, and a close collaboration with leading German raw material manufacturers, spurned the marketing and sale of Berstorff twin-screw extruders for an economical continuous preparation and processing of plastics.

For special process tasks, i.e. homogenizing, dispersion, filling and reinforcing, modifying, degassing and recycling of plastics, Berstorff twin-screw extruders in two-stage design are offered. In view of the future market development for reinforced and highly filled plastics, this sophisticated and technically outstanding ZE-A extruder series offers decisive economic advantages for the raw material manufacturer, the raw material refiner and the user itself. A substantial feature is the enlarged screw channel volume, allowing increased outputs at low melt temperatures. A number of local and foreign patents have been released for this optimized ZE/ ZE-A system and line concept, which can be micro-processor-controlled, if required.

Another major feature is the extruder's engineering which does not only include the individual machines and accessories but also incorporates the technology for each individual process requirement. Our engineering departments are specially laid out to design complete manufacturing lines, turn-key plants and grant know-how and training of customer personnel.

With this new series, Berstorff has undoubtedly set the trend for the future.



Building-block system of the ZE

Process-technical criteria

As already mentioned, the fields of application for twin-screw extruders are manifold and always connected with a high degree of process-technical know-how. New applications are permanently arising, has shown in the following examples:

— Change from discontinuous to continuous operation, resulting — for almost all mixing tasks — in an increased economic efficiency

— Compliance to higher legal standards, with regard to the residual monomer and solvent content

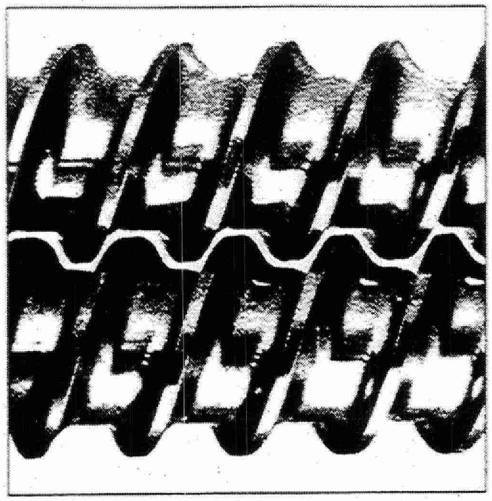
— Linkage of individual process steps

— Development of new engineering plastics for special applications and for low-scale production

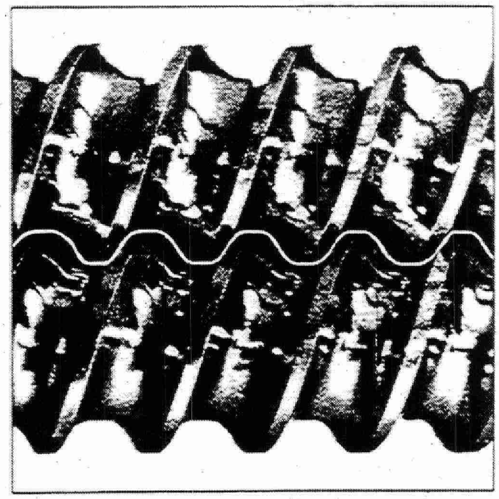
Due to their constructional and process-technical characteristics, Berstorff twin-screw extruders are optimal for accomplishing all extrusion tasks.

Building-block system

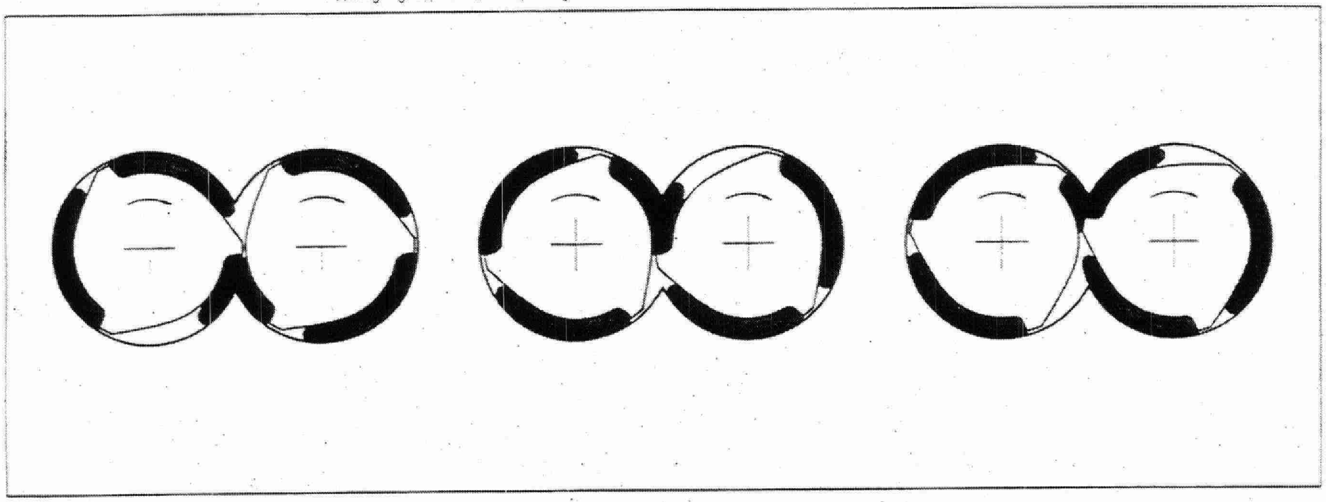
By using the Berstorff's building-block system, screw and barrel elements can be adapted to the specific task required. By applying the optimum screw geometry, barrels can be arranged accordingly for such tasks as conveying, compressing, homogenizing, degassing and pressure build-up. Our standard construction material for screw and barrel is nitrided steel. However, if required, other wear and corrosion protection options are available.



Pushing flight profiles, multiple-flighted



Transversally sealed profiles, multiple-flighted



Material exchange between extruder screws

Close-intermeshing screw profiles

Close-intermeshing of the screw profiles enhances short residence time thus avoiding thermal degradation of the product that would have resulted from a too long dwelling time. During a product change, cleaning times are minimized: moreover these screws enable a high pressure build-up as well.

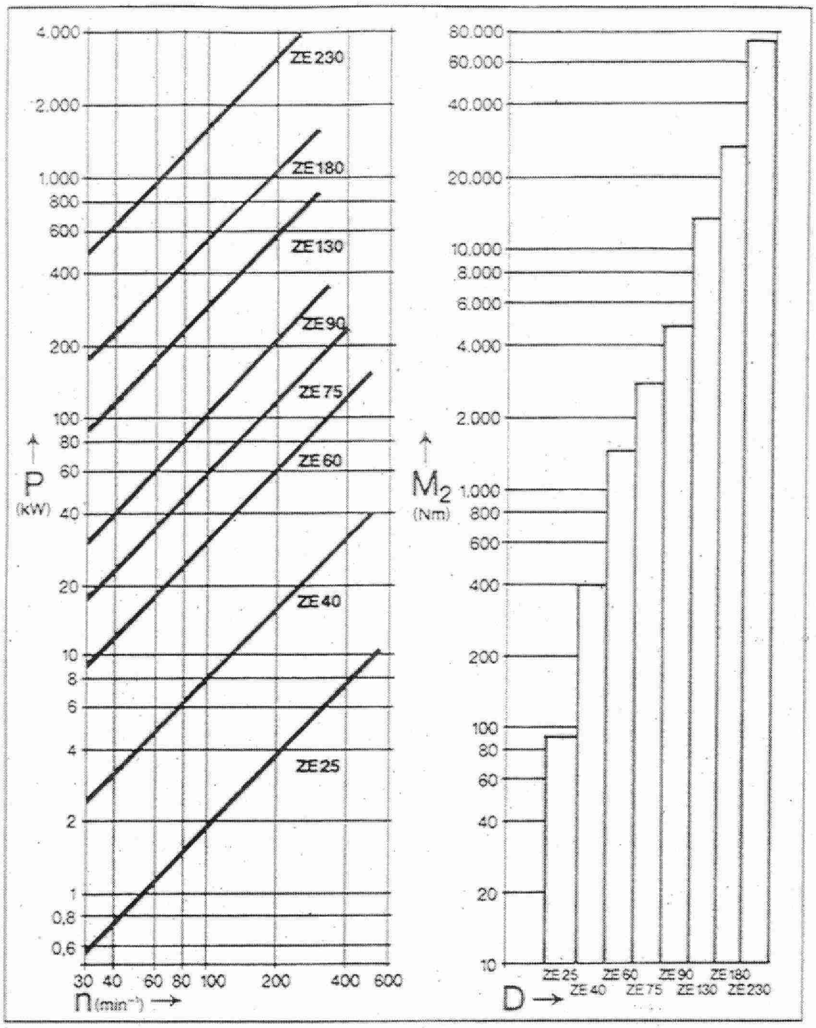
Reducing the screw flight width, i.e. enlargement of the gaps in the apex area, the chambers can be slightly opened, thus improving the longitudinal mixing effect. The self-cleaning properties of the screw channel remain practically unchanged.

For special process-technical tasks requiring complete intermeshing of the screws along a spatial curve with a narrow gap, »transversally sealed profiles« are available.

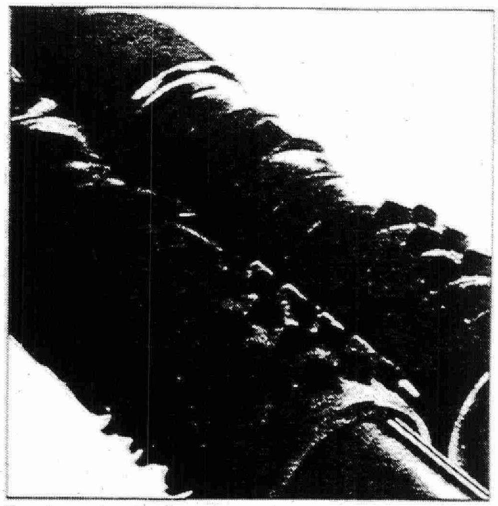
Co-rotating screws

Due to the design of co-rotating screws, high speeds and thus strong shearing forces and high outputs can be obtained. Compared with the counter-rotating twin-screw extruders, no additional radial forces result which would have led to an increased wear of the screw and barrels.

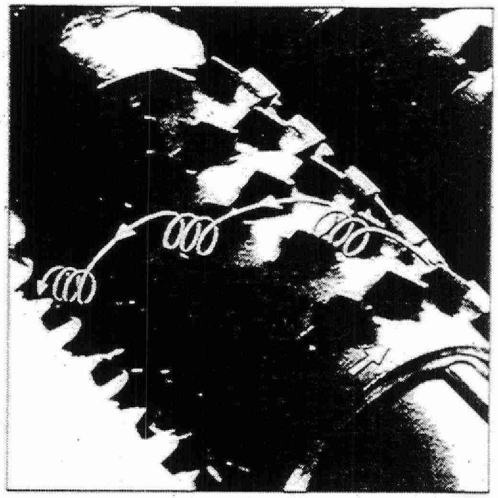
With the screws rotating in one direction, the material is transferred from one screw to the other and undergoes a constant mixing. This phenomenon is of special importance for a moderate and homogeneous mixing, and for the heat transfer from or to the surrounding inner housing wall. In addition, the material's intensive and constant surface renewal creates favourable degassing conditions.



Speeds, torques and driving powers for ZE extruders



Kneading and mixing elements



Flow direction in the mixing element (principle)

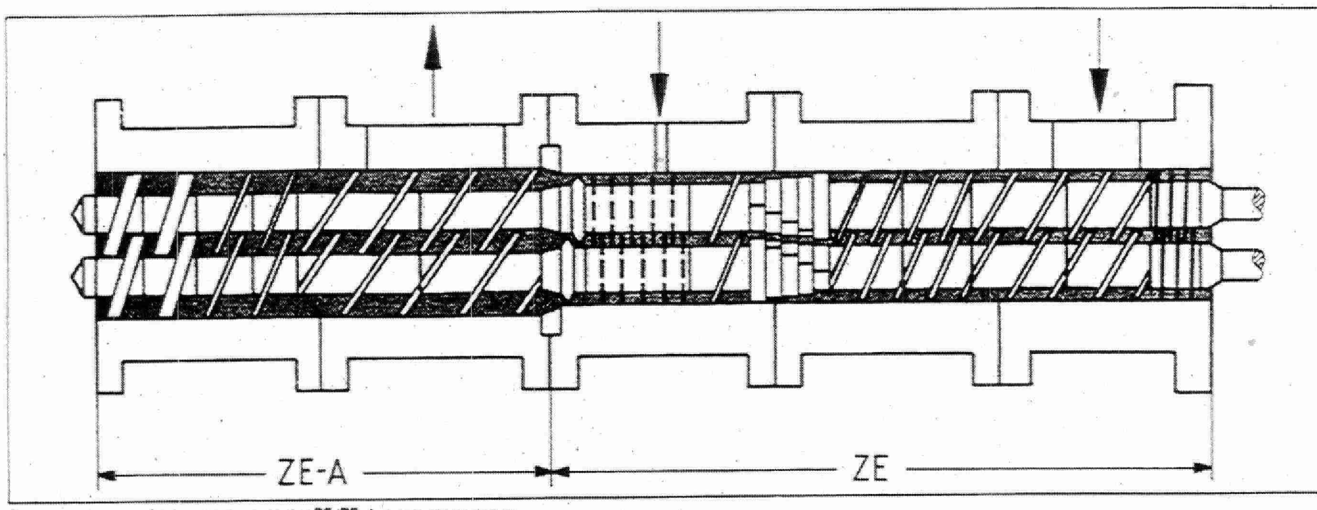
Kneading and mixing elements

By the use of conveying or retaining kneading elements, a good homogenization (dispersion) is achieved, while introducing high shear stresses. When changing the diameter, width or staggered position of the kneading elements, the energy introduction can be adapted to the product to be treated. The intermeshing of the kneading elements is effected along a spatial curve with constant gap.

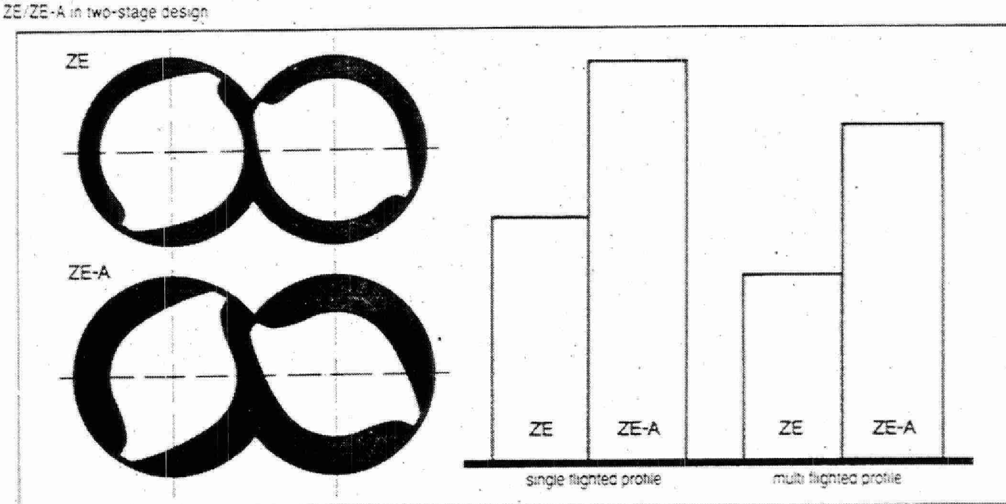
For careful mixing of the product, special mixing elements are applied. These elements are optimized with regard to a high mixing capability at low energy input. Such elements are used for adding glass, carbon or metal fibres, as well as for mixing products of different viscosities, such as polymers including solvents or stripping agents for degassing. This results at the same time in a frequent renewal of the melt surface while the efficiency of the mixing process remains unchanged.

High admissible screw torque

Gear unit and screw shafts are designed to transmit a high torque. Thus, the screw filling degree can in many cases be increased and the speed reduced. High outputs can also be achieved without exceeding the maximum admissible product temperature.



Sectional drawing of a twin screw extruder ZE/ZE-A in two-stage design



Ratio of the screw channel volume of the ZE to the ZE-A

ZE and ZE-A Two different diameter options are offered at the same screw centre distance

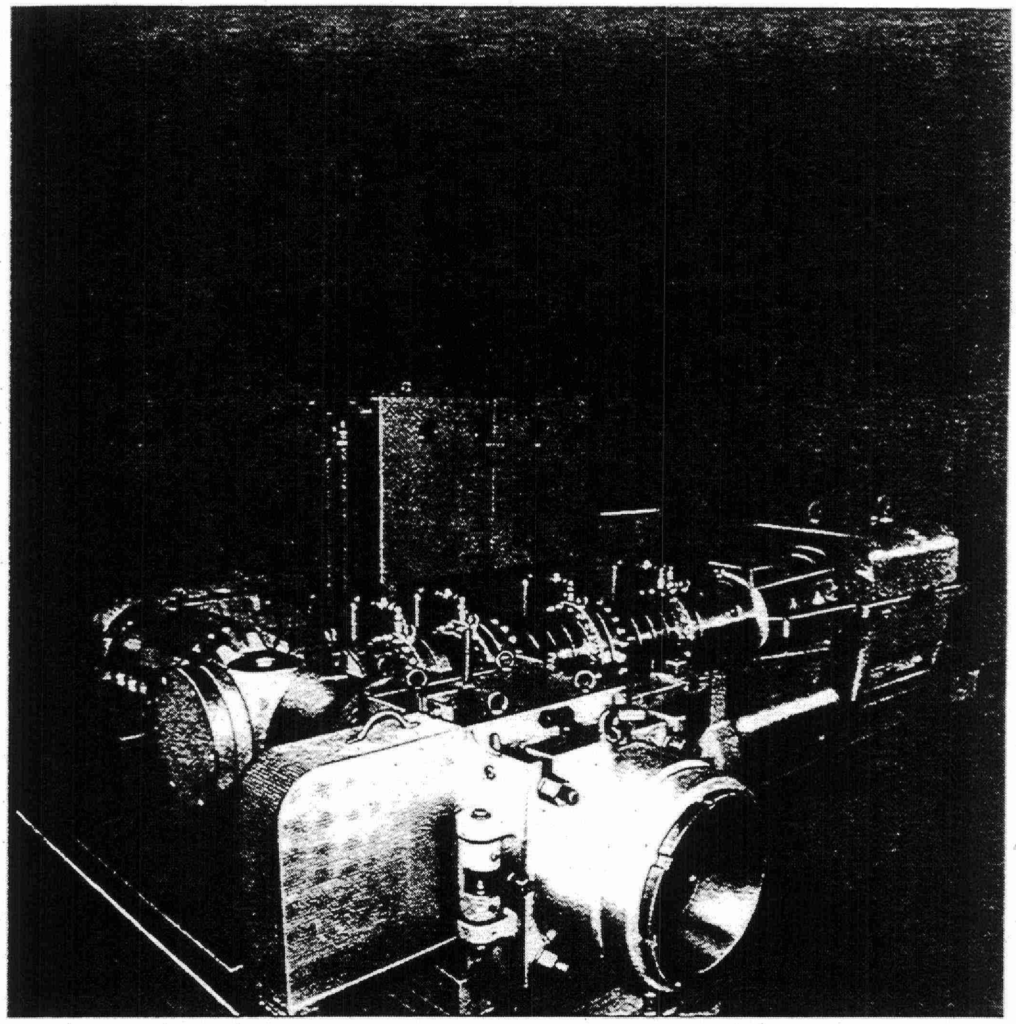
Due to two different diameters at the same screw centre distance, Berstorff twin-screw extruders can be applied for a large variety of tasks. Multiple thread screw profiles are available for both screw diameters along with a complete range of kneading and mixing elements which can be intercombined depending on the specific process.

The standard Berstorff ZE twin screw extruder with the smaller screw diameter and depth of screw flights is advantageous for a production requiring high shearing forces.

The ZE-A extruder with the larger screw diameter, larger flight depth and higher conveying volume is used for those productions requiring low shearing forces. The deeper screw flights reduce the shearing speed and stress at a constant screw speed. The ZE-A is an ideal machine to process shear and temperature sensitive materials. In the case of a higher shearing rate, the ZE-A can be operated at higher screw speeds, rendering a higher output.

The large conveying volume of the ZE-A extruder is particularly suitable for difficult-to-feed products, such as powder with low bulk density or fibre-loaded mixtures. The identical screw centre distance allows the two extruders to be combined into one*). If, for example, the pellet-fed ZE extruder undergoes a difficult degassing (low ppm values) and the melt's temperature is limited, a combination of the ZE and ZE-A is advisable. The devices the standard ZE is equipped with are those of feeding, solids conveying, plasticizing and the ones of the special ZE-A are those of degassing, homogenizing and pressure build-up.

*) Patents in Europe, USA, Japan



Extrusion line ZE 130 A/KE 200

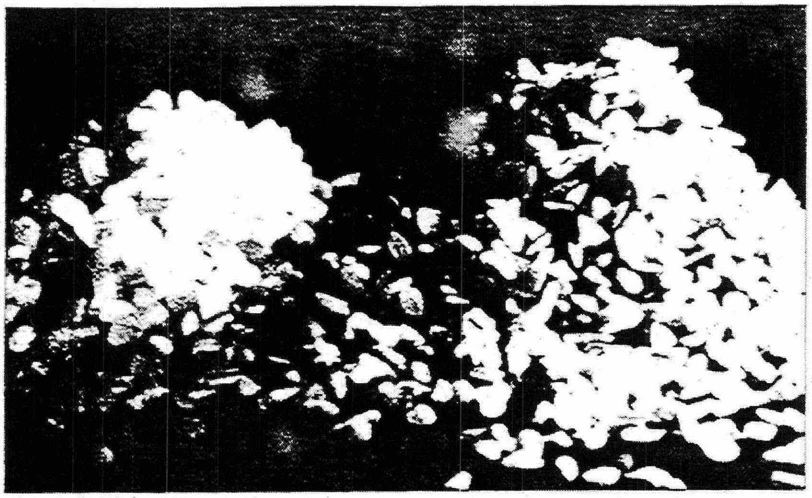
The ZE — KE Extrusion Line — A useful combination of two successful systems

When manufacturing compounds sensitive to temperature and shearing, it is more economical to separate the process technical steps: Plastification, degassing and discharging. The extruder ZE with the rapidly turning twin-screws compounds and degasses, whereas the extruder KE with the slowly turning deep-channel single-screw builds up the pressure required for discharging and pelletizing.

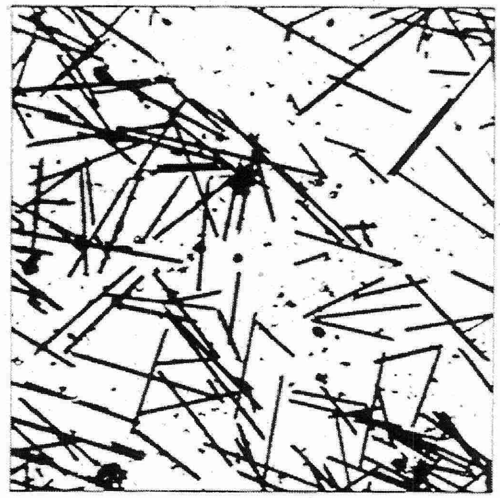
These lines are already being used efficiently, for example, for the preparation of crosslinkable PE (VPE), the production of PE-foam, the compounding of hot-melt adhesives, the preparation of butyl rubber and the processing of PVC.

In general, these two systems are arranged at a right angle to each other. If they are to be flanged together, then either the ZE or the KE is designed as movable and pivotable equipment. For special cases, both extruders can be arranged in parallel and connected via a heatable melt-conducting line, in this respect the degassing process takes place preferably in the single-screw extruder at slow speed.

Both extruders are provided with individually controllable driving systems and separate temperature control units. Cooling can be effected by a common group.The cut pellets are air-cooled during their conveyance to the relevant silos. The cooling capacity can be increased in special cases by an interconnected fluid bed cooler. In most cases, these lines are equipped with a hot die face cutting.



PA 6 and PA 6.6 with 60 % glass fibres



Minimal length reduction of the blended-in glass fibres

Process applications

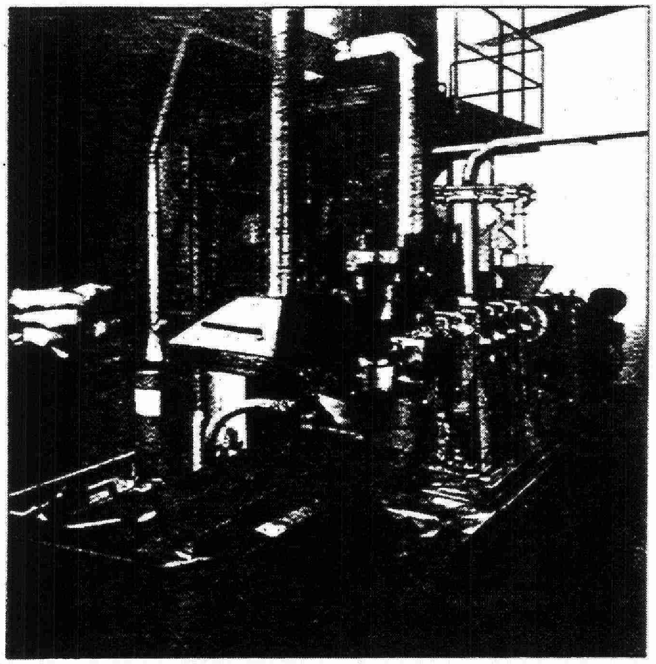
Typical process applications for the Berstorff close-intermeshing, co-rotating twin screw extruders ZE are:

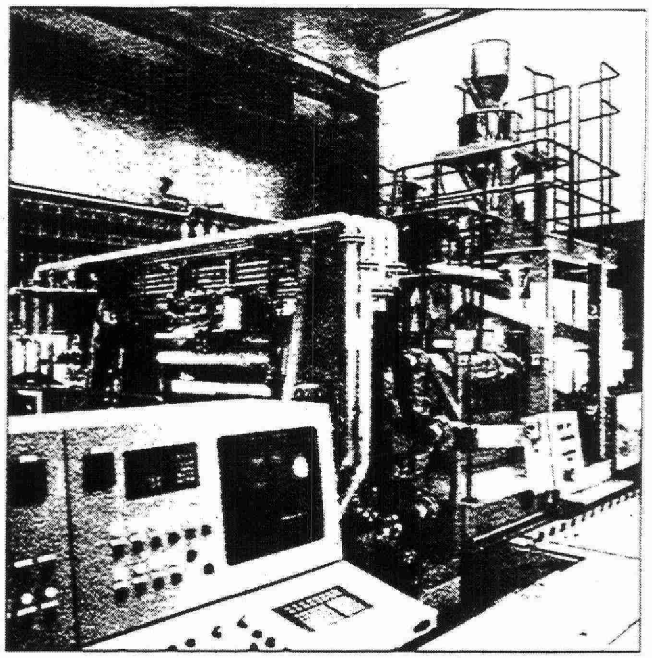
- Compounding of reinforcement and filler materials such as: Glass fibres, talc, limestone, wood dust, etc.
- Colouring and/or stabilizing of plastics
- Production of pigment, flame protection, blowing agent and filler concentrates
- Production of different plastics alloys and plastics elastomer alloys
- Homogenizing of products with varying viscosities
- Modifying plastics by incorporating additives
- Melting, homogenizing and pelletizing of powder with low bulk density, small grain size and low internal friction
- Degassing volatiles such as water, monomers and solvents
- Chemical reactions
- Polymerisation, post-condensation
- Repelletizing of ground materials and agglomerates, as well as film or fibre waste of low bulk density
- Recycling of, for example, butyl rubber

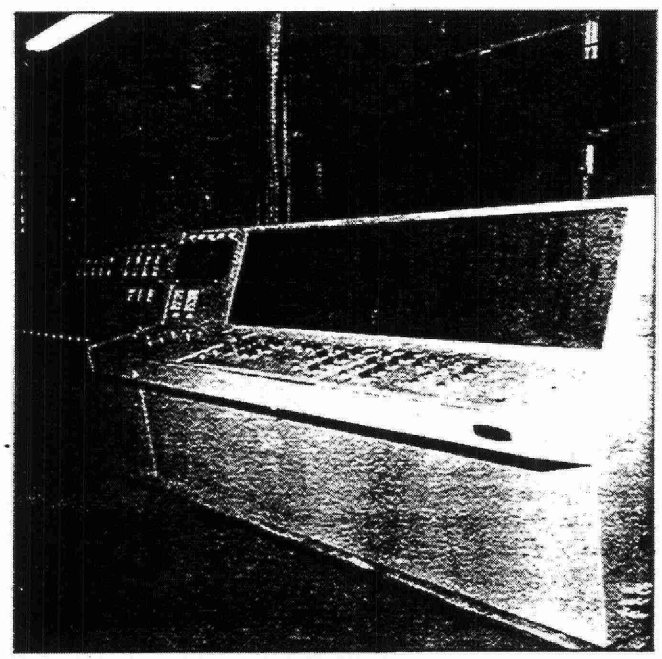
Products

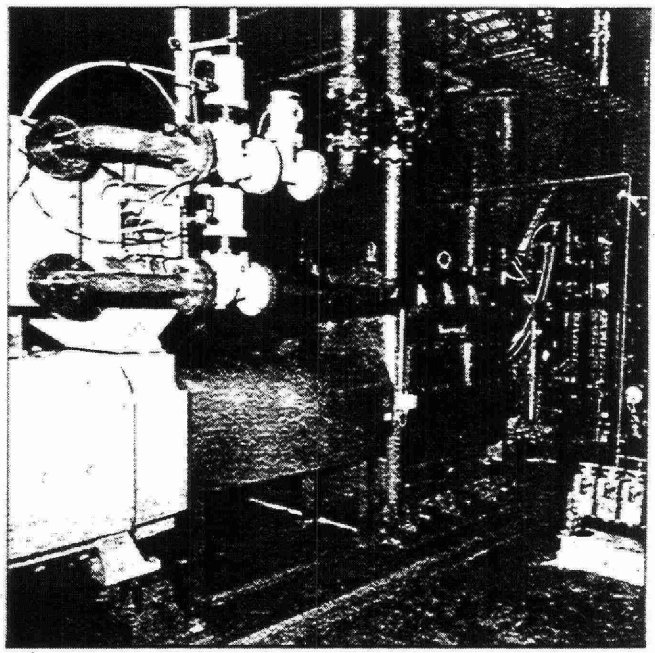
The process experience with the Berstorff twin-screw extruder ZE includes the following polymers:

- low-density polyethylene (LDPE)
- linear low-density polyethylene (LLDPE)
- high-density polyethylene (HDPE)
- polypropylene (PP)
- polystyrene (PS)
- styrene-acrylonitrile copolymer (SAN)
- acrylonitrile-butadiene styrene (ABS)
- polyamides (PA 6, PA 6.6, PA 12)
- linear polyester (PETP, PBTB)
- polycarbonate (PC)
- poylymethyl methacrylate (PMMA)
- polyphenylenoxide
- polyetherether ketone (PEEK)
- polypenylene oxide (PPO)
- polysulfone (PSU)
- polyvinyl chloride (PVC)
- polyvinyl butyral (PVB)
- polyoxymethylene (POM)
- fluoropolymers
- thermoplastic materials modified by elastomers
- elastomers, e.g. SBR, EPDM, silicone rubber
- thermoset materials, thermosetting moulding compounds, e.g. UP
- flooring materials
- powder coating, toner
- ceramics, catalysts, and catalyst carriers
- food







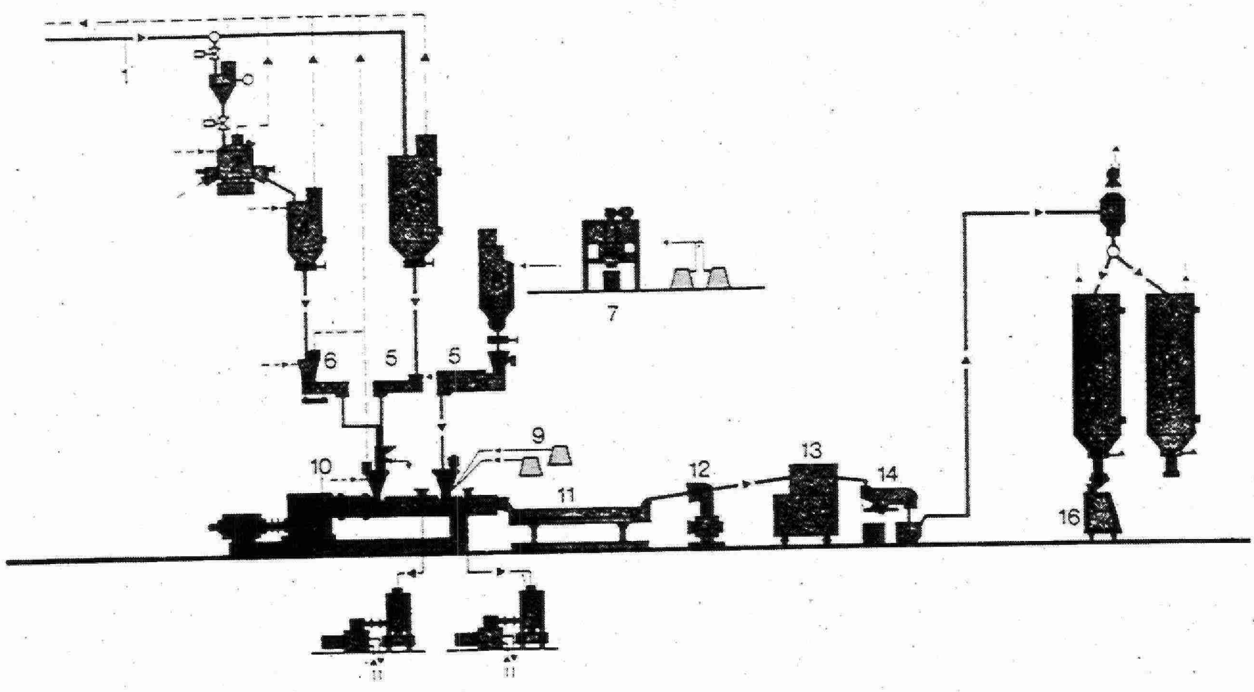


Examples of different ZE-lines

Examples of process applications

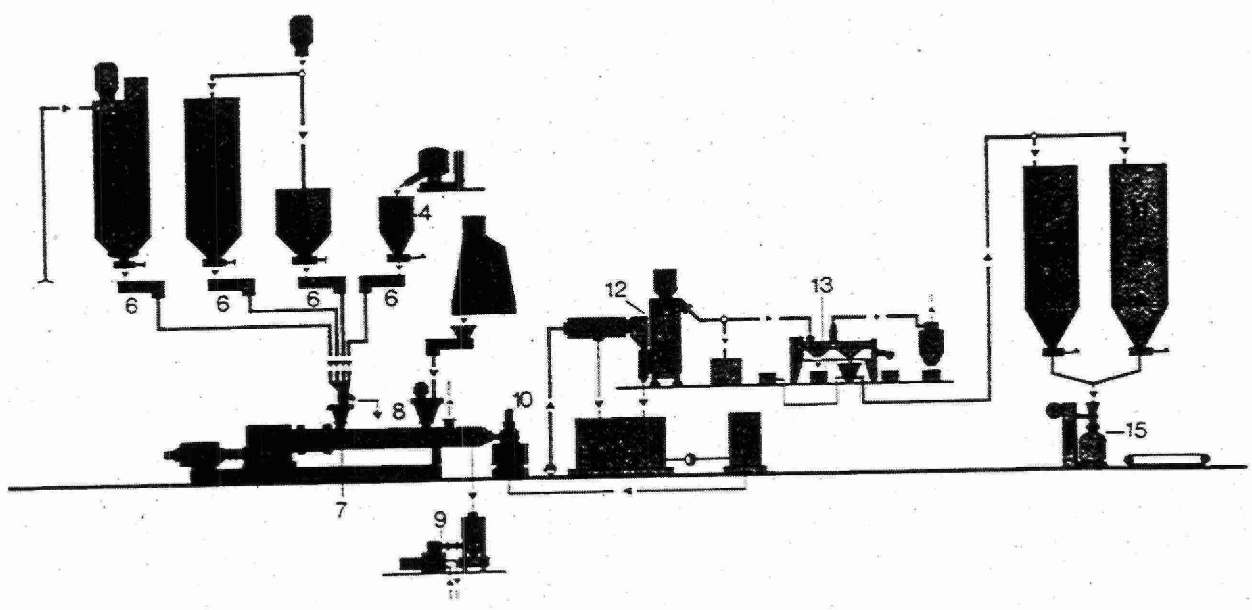
For most applications such as filling, reinforcing, alloying or reclaiming, a different combination and assembly of the machine, downstream equipment and special accessories are required. The flexibility is already designed into the ZE and ZE-A extruders, making this equipment highly suitable for these various applications.

The following pages provide some examples of complete production lines designed and supplied by Berstorff.



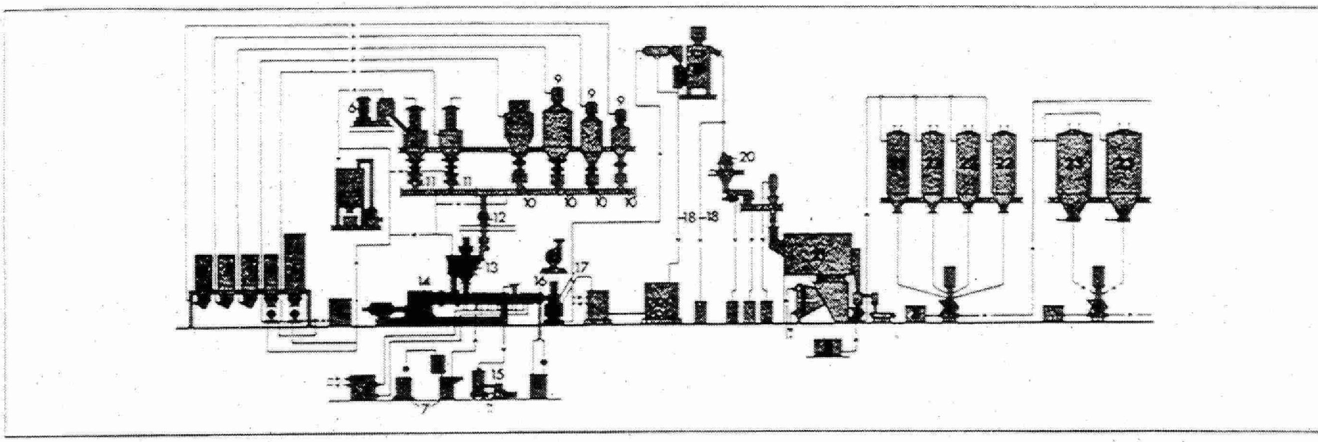
Line for reinforcing thermoplastics

1. Raw material supply
2. High speed mixer
3. Main product component storage
4. Pre-mixed component storage
5. Weigh belt feeder
6. Loss-in-weight feeder
7. Fibre cutter
8. Fibre storage
9. Glass roving supply
10. Twin screw extruder ZE/ZE-A
11. Water bath
12. Air knife
13. Strand pelletizer
14. Classifier
15. Silos
16. Sacking station



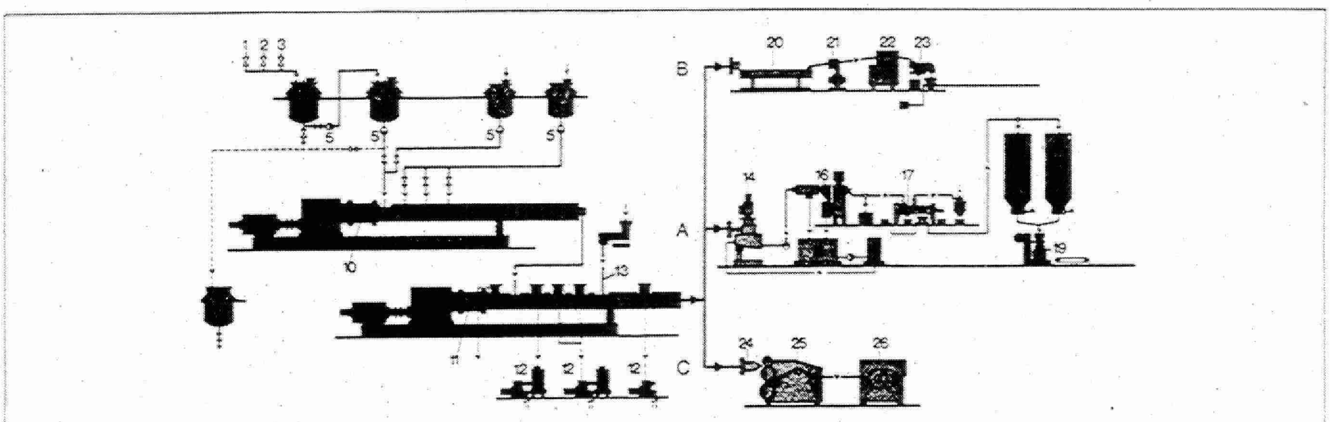
Line for alloying of thermoplastics

1. Storage PPO powder
2. Storage PS pellets
3. Storage PS reclaim
4. Storage additives
5. Glass fibre feeding
6. Loss-in-weight feeder
7. Twin screw extruder ZE/ZE-A
8. Downstream feeder for glass fibres
9. Degassing system
10. Water-ring pelletizer WRG
11. Transport water system TWS
12. Pellet dryer
13. Classifier
14. Silos
15. Weighing and sacking station



Line for filling of thermoplastics

1. Storage PP Powder
2. Storage PP pellets
3. Storage PP reclaim
4. Storage talc
5. Storage carbon black
6. Pigments blending
7. Liquid additives feeding
8. Pressure conveying system
9. Vacuum conveying system
10. Weigh belt feeders
11. Loss-in-weight feeder
12. Continuous mixer
13. Forced feed device
14. Twin screw extruder ZE
15. Degassing system
16. Screen changing equipment SW
17. Water-ring pelletizer WRG
18. Transport water system
19. Pellet dryer
20. Hammermill
21. Dryer
22. Test material silos
23. Main pellet storage



Lines for the polymerization of thermoplastics

1. Monomer
2. Monomer
3. Monomer
4. Weighing and mixing vessel
5. Pump
6. Intermediary vessel
7. Initiator vessel
8. Catalyst vessel
9. Reject vessel
10. Polymerization extruder ZE
11. Degassing and compounding extruder ZE
12. Vacuum und condensation unit
13. Additive feed

A) Waterring granulation

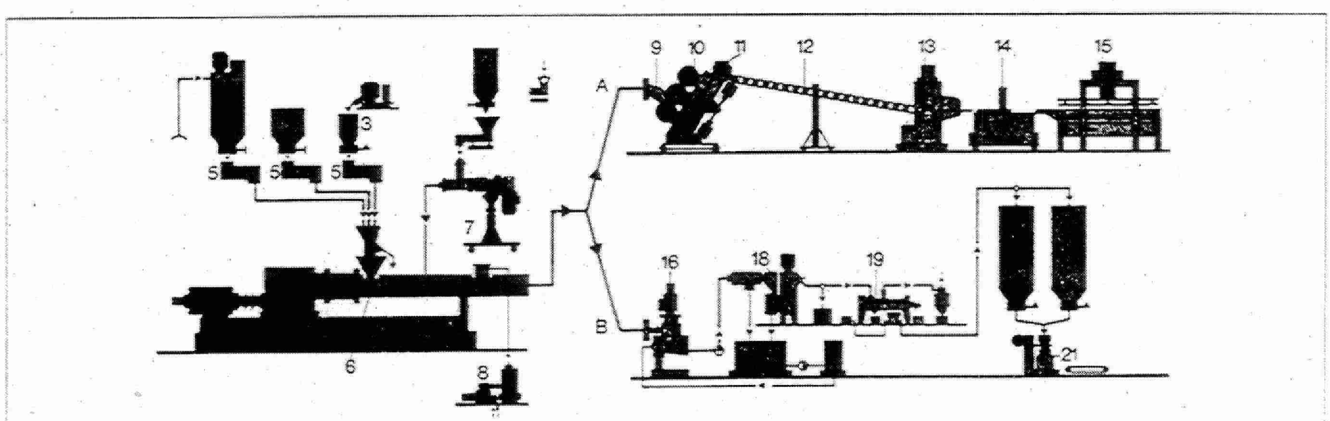
14. Waterring pelletizer WRG
15. Transport-water circulation system TWS
16. Pellet drying
17. Pellet classification
18. Product silo
19. Weighing and sack-filling station

B) Strand granulation

20. Water trough
21. Blow-up device
22. Strand pelletizer
23. Pellet classification

C) Production of flat films

24. Flat sheet die
25. Chill roll unit
26. Winding machine



Lines for the filling and reinforcement of thermoplastics

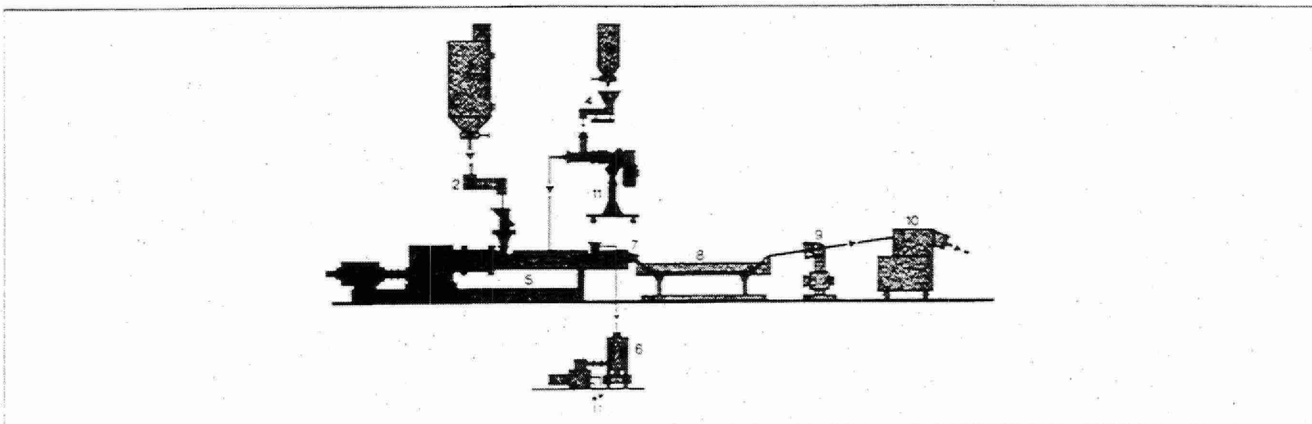
1. Polymer
2. Reclaimed material
3. Additives
4. Filters
5. Dosing device
6. Twin screw extruder ZE
7. Lateral dosing device ZSFE
8. Degassing

A) Production of filled sheets

9. Flat sheet die
10. Smoothing calender
11. Thickness gauge
12. Roller conveyer
13. Take-off and edge-trimming device
14. Cross-cutting device
15. Stacking station

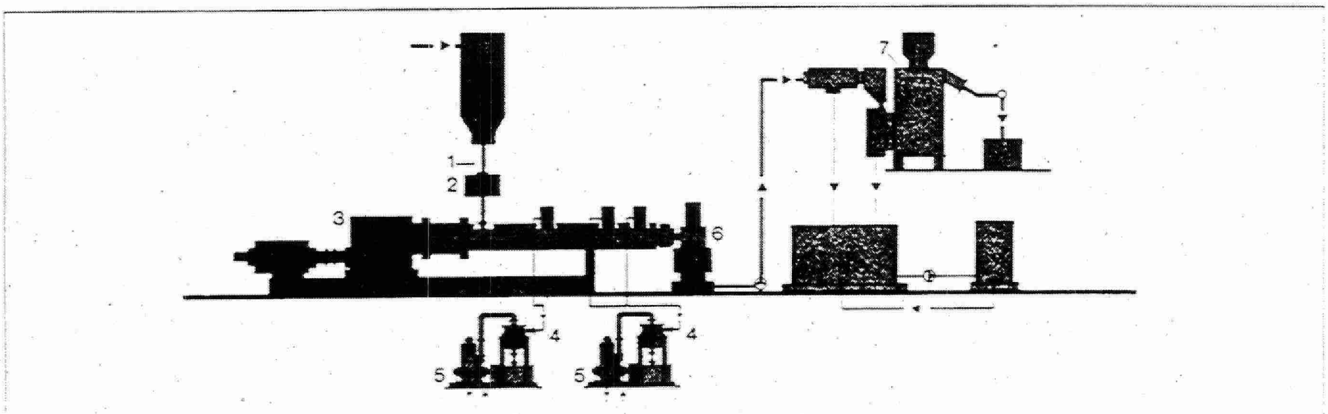
B) Production of filled pellets

16. Waterring pelletizer WRG
17. Transport-water circulation system TWS
18. Pellet drying
19. Pellet classification
20. Finished product silo
21. Weighing and sack-filling station



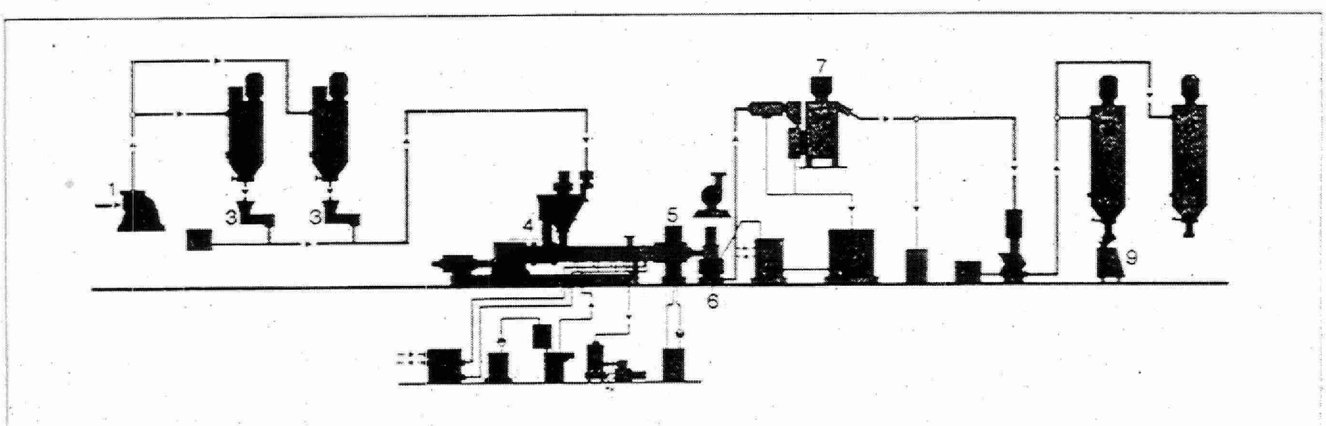
Line for the production of colour concentrates (masterbatch)

1. Thermoplastics storage
2. Weigh feeder
3. Pigment storage
4. Loss-in-weight feeder
5. Twin screw extruder ZE
6. Degassing system
7. Strand die
8. Water bath
9. Air knife
10. Strand pelletizer
11. Lateral dosing device ZSFE



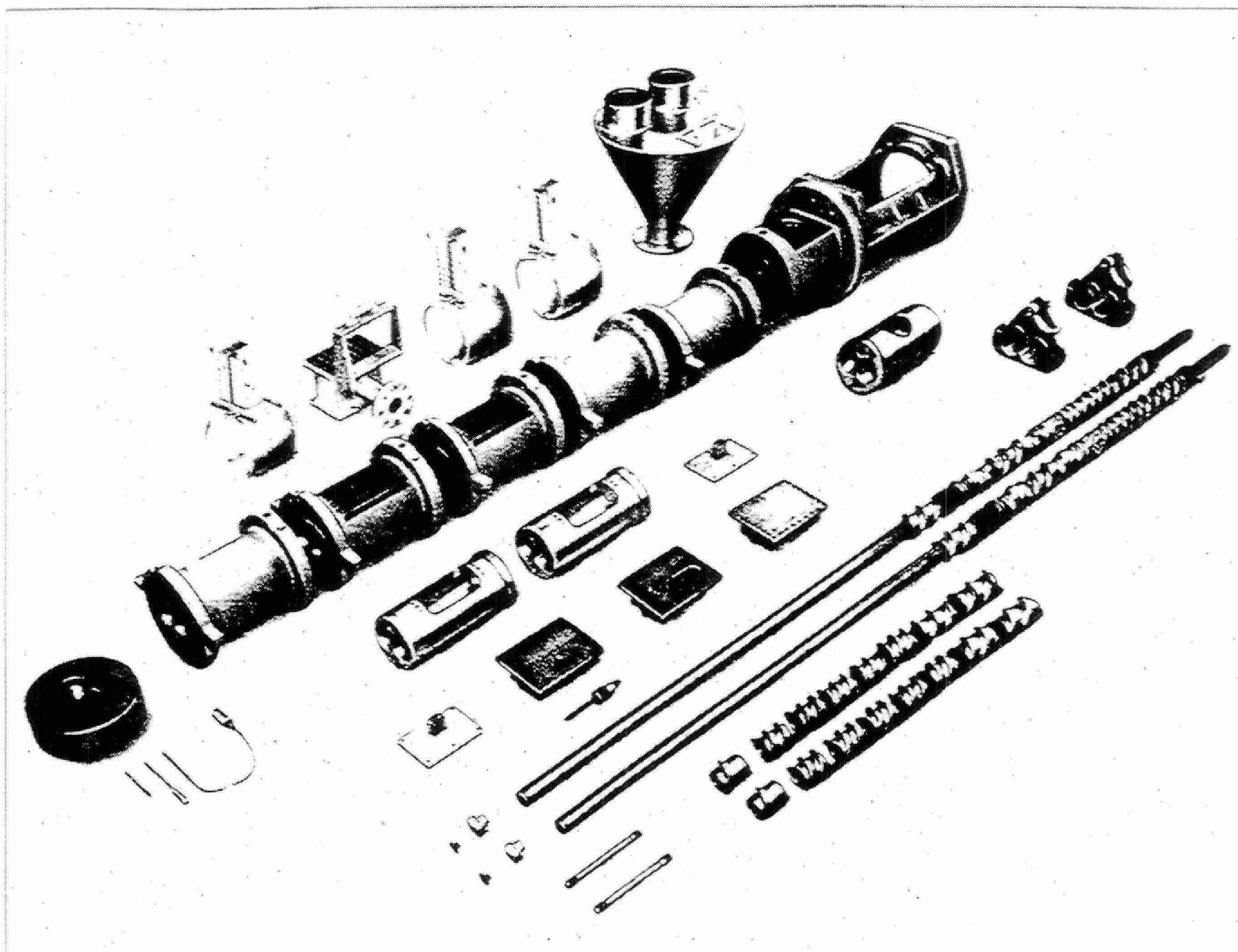
Line for degassing of thermoplastics

1. Polymer and solvent
2. Gear pump
3. Twin screw extruder ZE-A
4. Condensers
5. Vacuum pumps
6. Water-ring pelletizer WRG
7. Pellet dryer



Line for scrap reclaiming with degassing capability

1. Mill
2. Mixing silos
3. Conveying screw
4. Twin screw extruder ZE
5. Screen changing equipment CMF
6. Water-ring pelletizer WRG
7. Pellet dryer
8. Storage
9. Bagging station



ZE/ZE-A components

Constructional elements

Drive

The extruder can be driven either by an A.C., D.C. or hydraulic motor. Depending on the application, the speed can be either constant or variable. All the system's parts with critical functions are electrically interlocked so that in the event of a malfunction, the extruder and auxiliary equipment are immediately cut-off. As a standard, all extruders are equipped with an adjustable torque limiting coupling. In case of a malfunction, the drive and the extruder are immediately disconnected, under no load.

For all types up to the ZE 90, the drive's motor can be either directly coupled or connected to the gear unit by a V-belt drive. In case of the latter, the motor can be arranged in accordance with the local conditions.

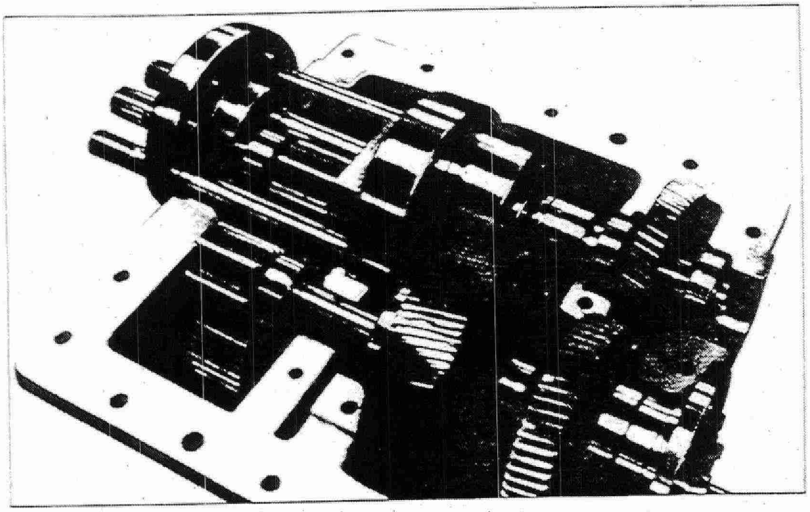
Gear Unit

The gear unit specially designed, developed and patented for our twin screw-extruders (FRG Patents 28 52 445/30 09 398), effects, on the basis of slight technical modifications, the co-rotation of the screw drive shafts.

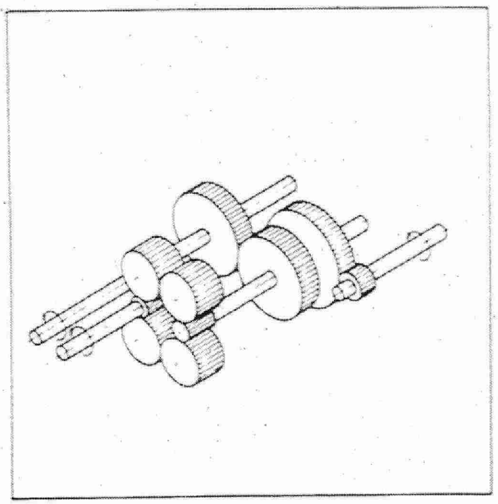
The gear unit is constructed in such a way that each screw has its own set of gears. These are connected firmly in the gear unit by a rigid tooth coupling. The power transmission to the individual screw drive shafts is effected from the respective reduction gear by power-branching intermediate gears. This intermediate gear arrangement provides double meshing of the gears, so that a high torque can be transmitted at relatively small forces. Using this principle, the radial forces of the gears are compensated for, thus not requiring any special bearings.

All gear parts are made of high-alloy, forged, case-hardened steel. The gear wheels are case-hardened and ground.

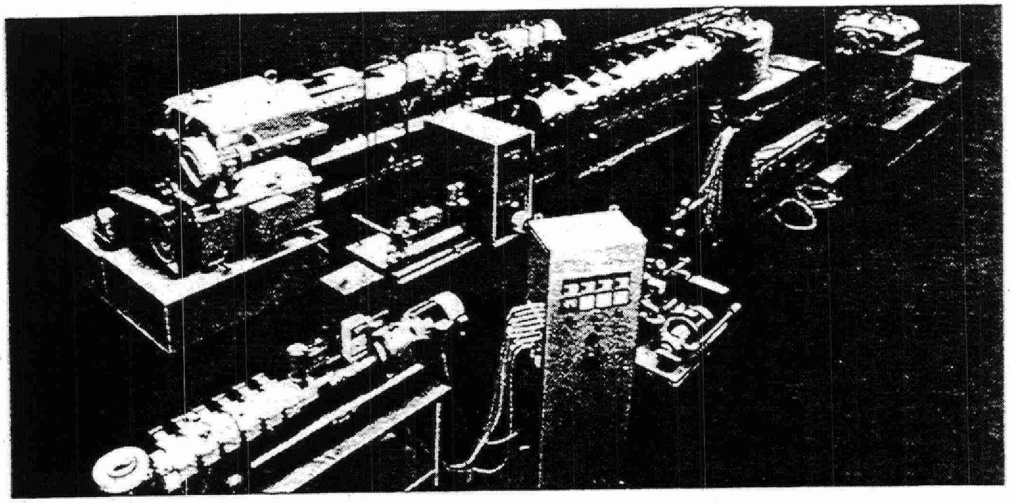
Lubrication is applied by oil injection. Bearings and gear parts are lubricated through pipings in the gear casing.



ZE gear unit



ZE gear unit scheme



ZE erection

Thrust bearing

The thrust bearing arrangement (for absorbing the axial forces acting in the extruder processing section) is an independent sub-assembly and, as such, an integral component of the gear unit. The use of both, dual tandem bearing and axial self-aligning roller bearing, allow the transmission of high dynamic loads. Only standard bearings are used. Built-in oil supply lines ensure safe lubrication.

Circulatory oil lubrication

A separate oil pump is provided for the gear unit and thrust bearing. The oil is cleaned by gap and magnetic filters. Oil cooler, pressure monitor and gauge are provided as a standard.

Barrel *)

The extruder barrel consists of individual barrel sections of 4 or 5 D length each and, in special cases, of 2.5 and 7.5 D length, bolted together and interchangeable.

Each barrel section can be provided with bores closed by inserts. These inserts are either tapped for installing thermocouples, pressure pick-ups, or provided with openings for the dosing of liquid additives.

For various process tasks, the barrel sections are available as closed ones or with large degassing openings. By replacing the degassing insert by a dosing one, a dosing barrel is obtained. The filler and reinforcing materials can be blended horizontally or vertically.

The barrel sections can be supplied either in a standard design, as one piece of nitrided steel, or with inserted exchangeable round liners made of nitrided steel, or with a bimetal lining. For aggressive products, the barrels can be equipped with exchangeable liners with special bimetal lining or made of through-hardened steel.

The barrels are designed for electrical heating and water-cooling or, in special cases, air-cooling.

Heating/cooling can be effected by liquid, using organic thermal oil, pressurized water or steam. The cooling system is dimensioned so that the main part of the shearing energy in the product is dissipated through the barrels.

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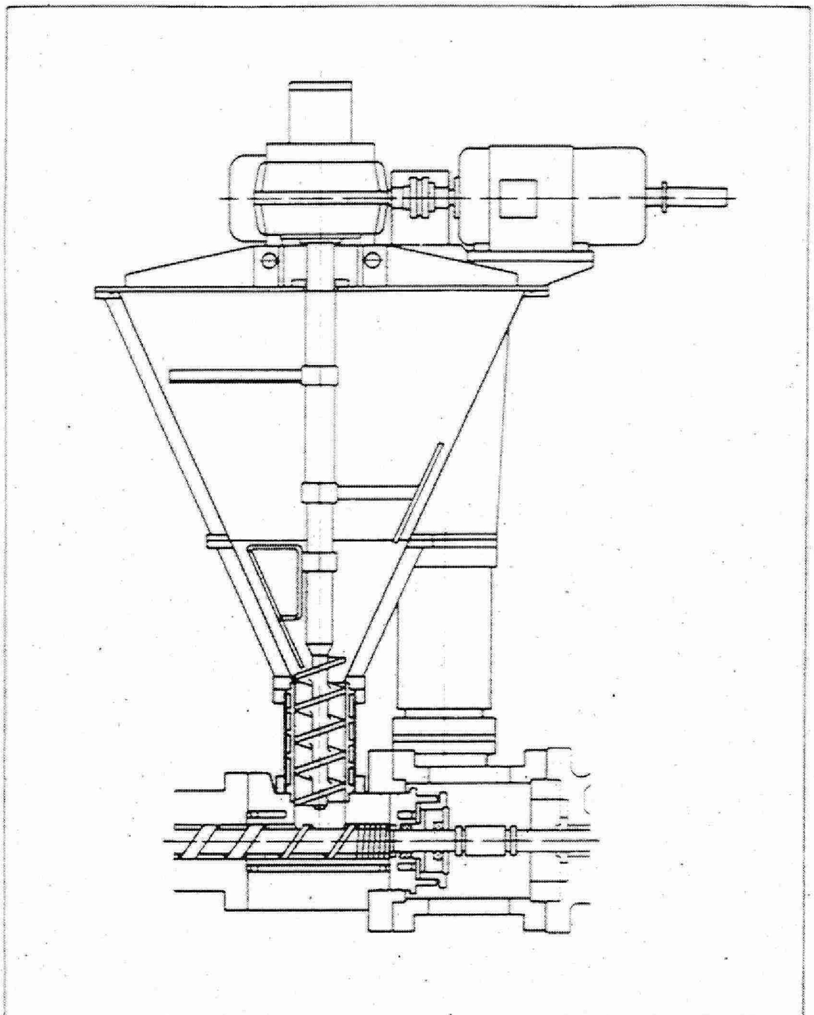
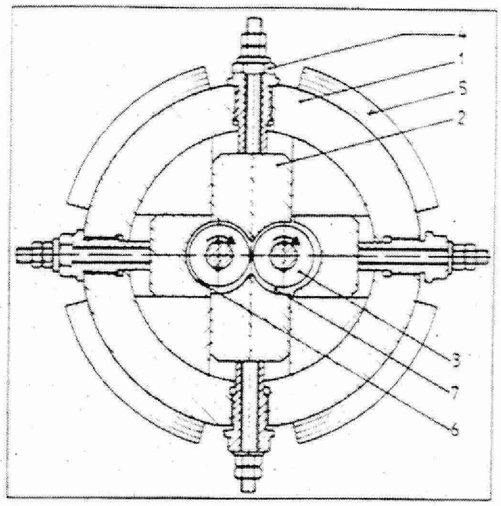
*) FRG patent 26 59 037
FRG patent 29 22 572
Europ. patent 0 042 466



Filling zone with forced-feed device



Continuously adjustable throttle unit

1. Housing
2. Flat slide
3. Blister
4. Adjusting screw
5. Heating
6. Gap, closed position
7. Gap, open position

Throttle unit *)

The mechanically infinitely variable throttle gap influences the residence time and the filling level and, consequently, the degree of plastification in the melting area. In this way, a maximum adaptation to products with varying flow characteristics is achieved without having to change the screw profile.

The throttle unit is available for new equipment and can also be fitted into already existing extrusion lines.

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*) FRG patent 30 42 427

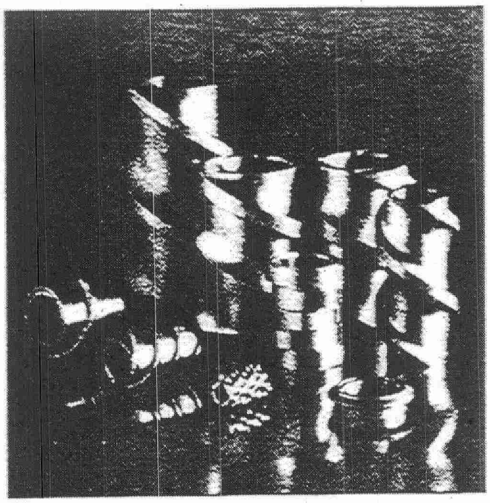
Feed section

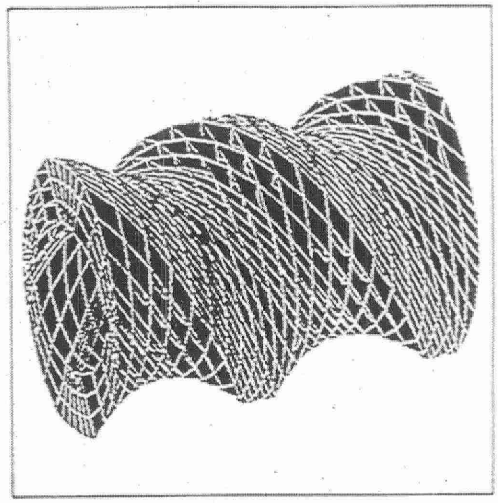
The feed section consists of the actual feed hopper and the adapter which separates — thermally speaking — the processing section from the drive. The feed opening is placed in the centre of the feed section and is used for mounting a forced-feed or dosing system. In order to avoid premature melting in the feed section, cooling facilities are provided. The return scroll seals against back-flowing material. Optionally, a coolable packing gland can be supplied for gassing and degassing processes, or if powder is fed.

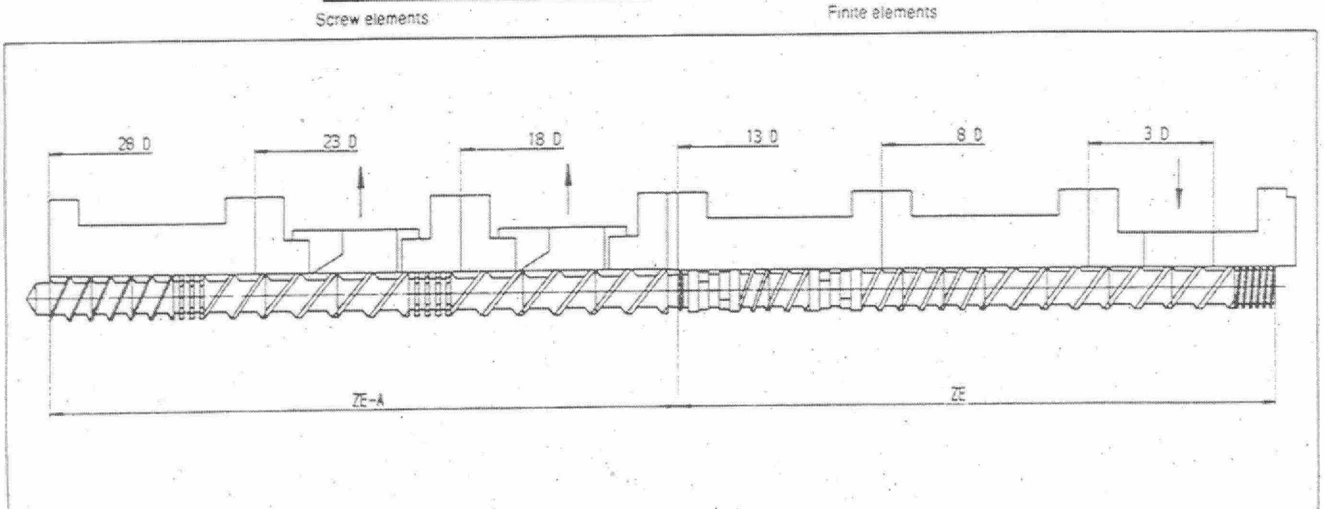
As a standard, a radial bearing unit is mounted behind the gland, allowing safe operation of the latter. It also ensures an exact centering of the screws in the solids conveying section so that metallic contact of screw flight with the barrel's bore is absolutely avoided, even during force-feeding.

If the process necessitates a gas sealing, as for instance in melt-fed extruders, a sealing gland with double sliding rings and a pressurized blocking liquid system is installed. This ensures a gas impermeability up to 25 bar.

The adapter has large openings enabling maintenance work without having to remove unnecessarily parts which are not subjected to it.


Screw elements


Finite elements



CAD-drawing of the screw design

Extruder screws

The screws consist of continuous shafts onto which the various elements are mounted (FRG Patent 27 40 028). The screw assembly is generally composed of conveying, shearing and mixing elements. Each screw configuration can be easily attained due to a wide selection of screw elements, thus allowing a great versatility and adaptability to new processes.

After their mounting on the shafts, the screw elements are pretensioned with the screw tip.

Cup springs compensate the thermal expansion between shafts and screw elements.

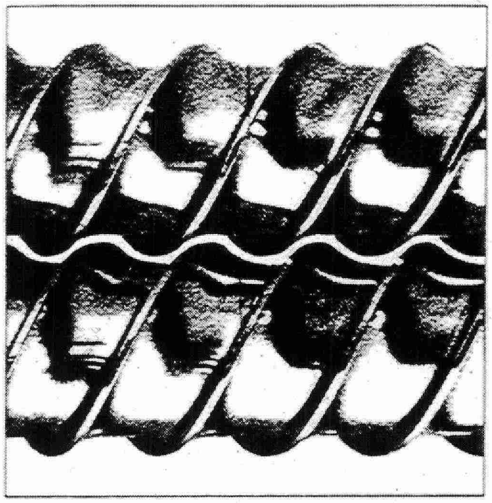
Two round keys, in staggered position, transmit the torque of the screw shafts to the individual screw element. This design prevents the grooved sections of the screw elements from undergoing excessive stresses. The advantages in this respect are:

- Easy assembly and disassembly of the screw elements,
- No angular misalignment when assembling the individual screw elements,
- No restrictions with regard to the selection and heat treatment of the screw material.

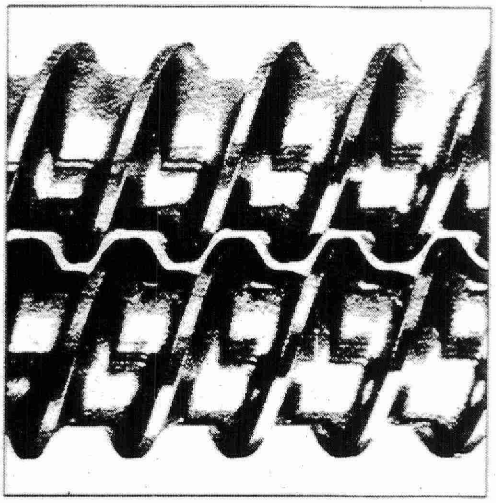
Nitrided steel screw elements are standard. However, for processing highly abrasive and corrosive materials, special wear-resistant screw elements can be applied.

The screws can be extended, sectionwise, on the basis of the building-block system. The torque is transmitted from the gear unit to the screw shafts by internally geared bushings.

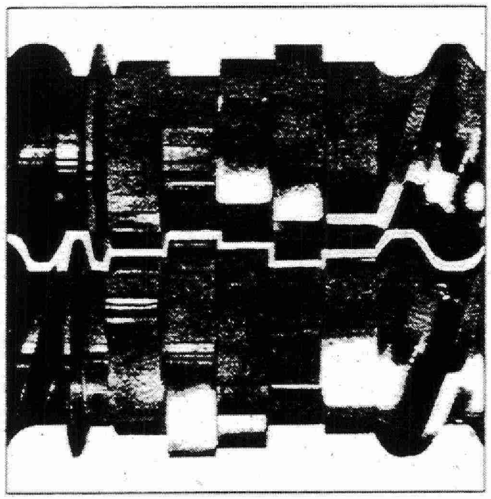
For special process tasks, the screws of the extruders from the ZE 60 onwards can be optionally heated/cooled. Feed and return of the heating/cooling media occur via the relevant connection arranged in the adapter. Extruders can be modified accordingly.



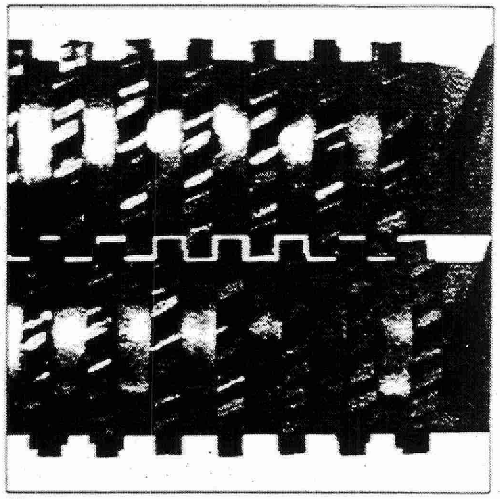
Pushing flight profiles, triple-flighted



Pushing flight profiles: double-flighted (A-version)



Kneading block



Mixing elements

Conveying elements

Conveying elements are used in the feed, transport, pressure build-up and degassing zones.

The screw profile has nearly closed channels to allow, if necessary, a high pressure build-up. In this way, pressure consumers (such as shearing and mixing elements) can be placed one behind the other over a short length thus minimizing the extruder length.

The conveying section obtains open screw chambers by reducing the screw flight width or the core's diameter. Mixing of the melt can take place through the gaps so that the elements function like agitators, providing optimum longitudinal mixing. The conveyed quantity and therefore the residence time are intentionally influenced by a leak flow.

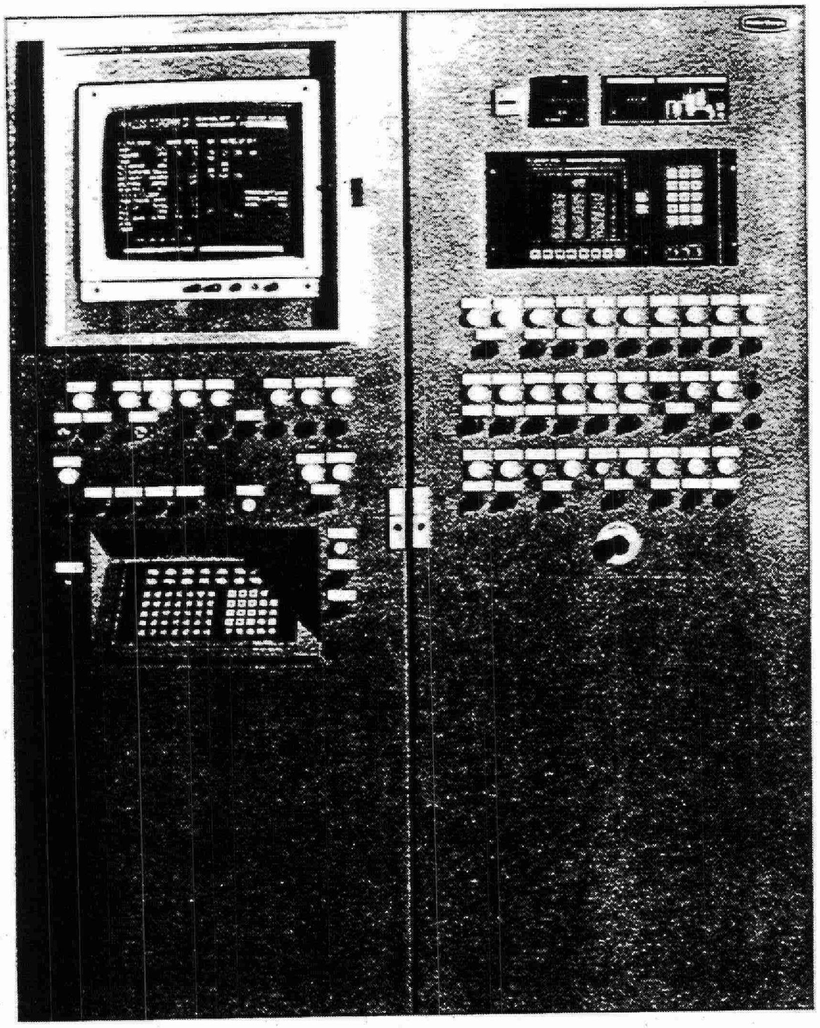
Multi-threaded conveying elements with varied pitch are used for modifying the free screw volume and the densifying materials of low bulk density.

Kneading elements

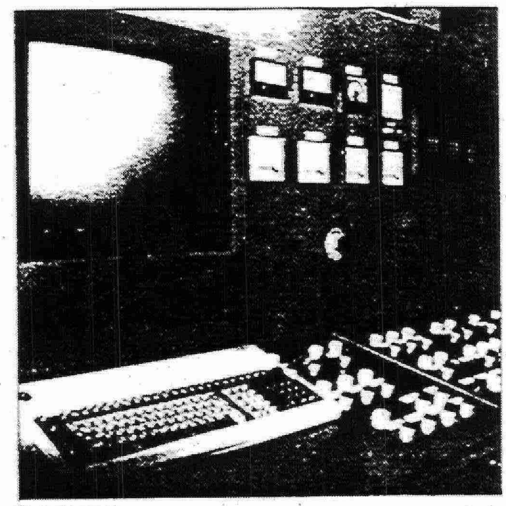
Kneading elements, with defined shearing gaps arranged on their circumference, are suitable for the melting and crushing of additives and for the homogenizing of polymers. These kneading elements are designed as blocks or as individual disks arranged behind each other and cause, if their arrangement is staggered either to the left or right, an additional intensive mixing.

Mixing elements

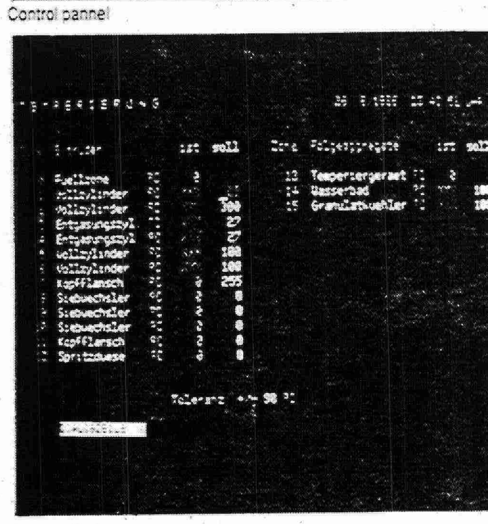
Mixing elements are advantageously applied for mixing liquids, powder or fibrous additives even in smallest concentrations. A mixing section consists of one or a series of toothed disks which can be varied in the number, width and shape of the teeth. The toothed disks are optimized with regard to their mixing properties at a minimum pressure loss.



Process-control system



Control pannel



Monitor display

Automation

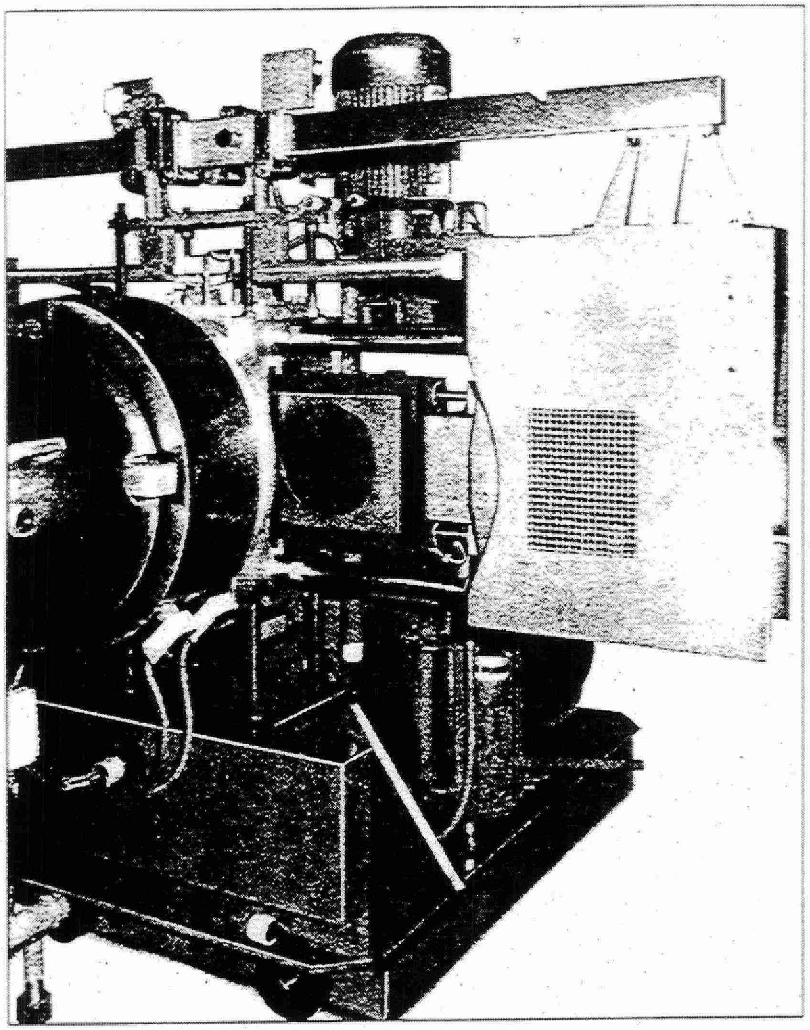
The efficiency of the high-performance twin-screw compounding lines is increased even more by an automation system, developed especially for this purpose. Its main functions are the control and monitoring of the extruder and all peripheric devices, such as dosing, vacuum and pelletizing devices. Furthermore, this system allows the optimization and control of processes including the acquisition of all essential operation and product parameters, i.e. melt temperature and pressure, torque, temperature profile and throughput.

These coordinates are evaluated and constantly compared with the admissible limit values, thus allowing an optization of the throughput or a minimization of the melt temperature.

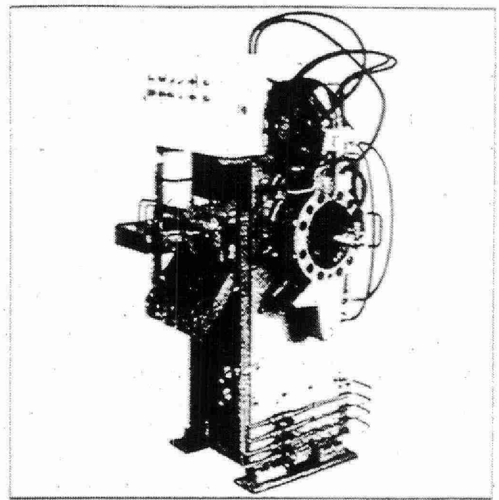
Other advantages are the continuous monitoring and recording of the process itself and the registration/display of malfunctions.

The main functions of the control are: Heating-up, dialog-based start, production, production end at achieved predetermined charge quantity. Additionally, emergency stops are programmed in case of machine trouble.

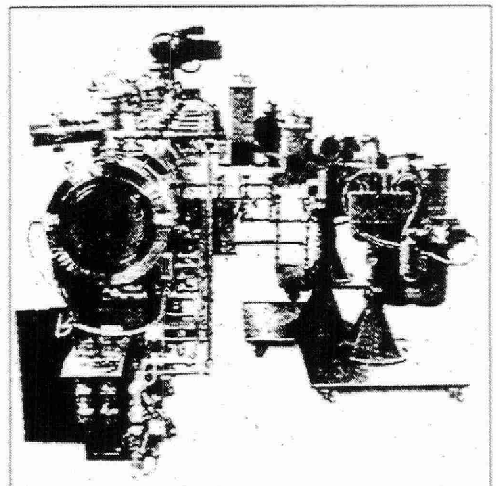
The automation system is conceived to be extended to all functions so as to have an overall control of the complete extrusion line: From the availability of raw materials to the packing of the finished product. Interfaces allow the connection to the master computer thus allowing an optimal compliance of the Berstorff extruders to the specifications of the clients.



Screen changing equipment SW



Melt filter unit CMF



Lateral dosing device ZSFE with agitator

Accessories

Twin-screw lateral dosing system - ZSFE

The twin-screw lateral dosing system ZSFE is intended for the feeding of either light, or fluidizing, or poorly flowing, or wall-adherant fillers or additives. Depending on the flow characteristics of the product to be fed, the screws can be either co-rotating or counter-rotating. The speed of the screws is modifiable via a mechanical variable-speed gear unit or via D.C. or frequency-controlled motors. When connecting the dosing system horizontally and laterally to the extruder barrel, it can be designed as movable equipment in order to minimize idle times during product change. In special cases, a vertical mounting position, when degassing agglomerated product at high gas speeds, avoids aspiration of the product and ensures a flawless production.

Screen changing equipment *) - SW

Electro-hydraulically operated screen changing units allow a quick change of the screens without having to carry out major dismantling work or interrupt the production.

When changing the screen, the following functions are carried out automatically:

- The gasket is released hydraulically,
- The slide plate with the new screen is pushed into the product stream,
- The melt seal is re-tensioned by cup springs.

*) FRG patent 30 43 217

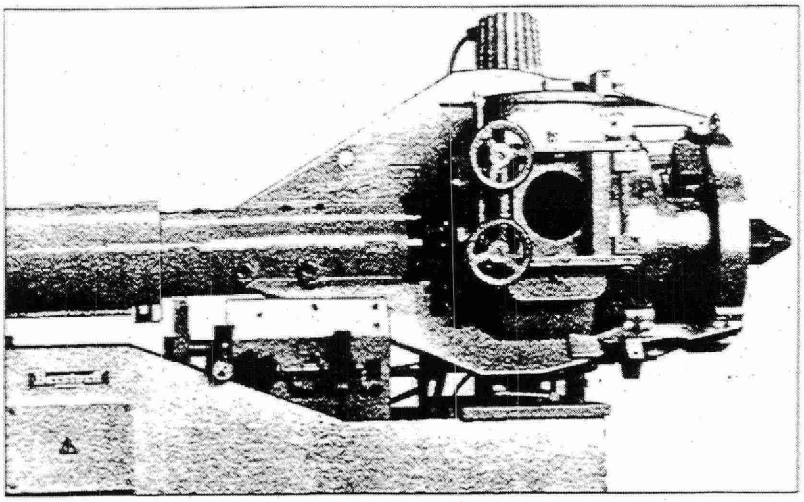
Continuous melt filter *) - CMF

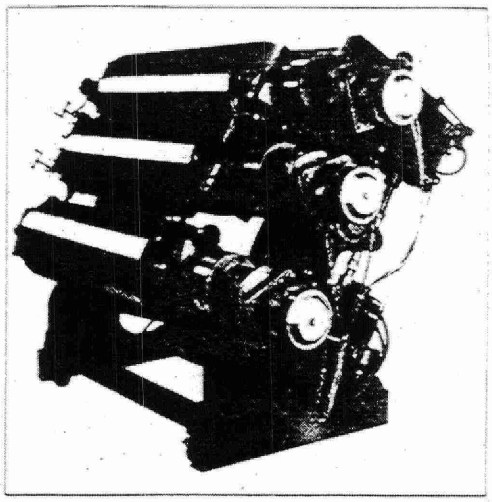
This newly developed continuous melt filter unit to filter solids from thermoplastic melts and to separate solids out of liquids, can be fitted to any existing single or twin screw extruder.

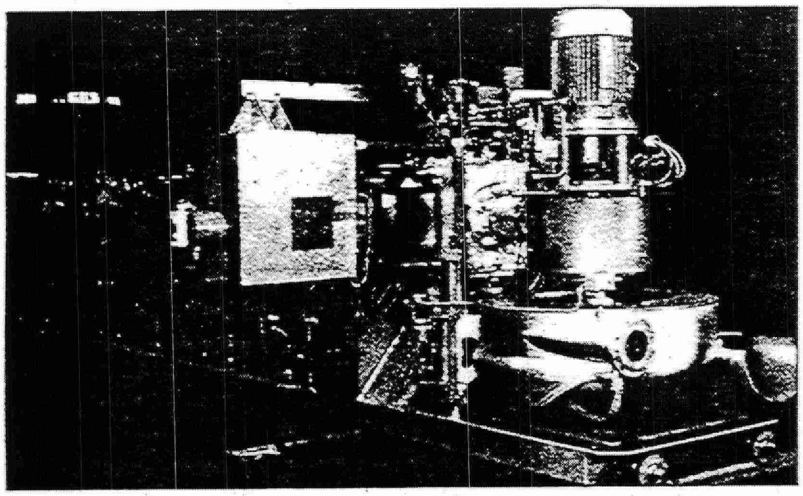
At a net screening area of e.g. 730 cm^2, the output capacity amounts to 500 — 3000 kg/h. The CMF unit operates on the principle of a rotating cylindrical hollow screen element. The impurities are separated via specially designed and hydraulically lockable back-purging openings.

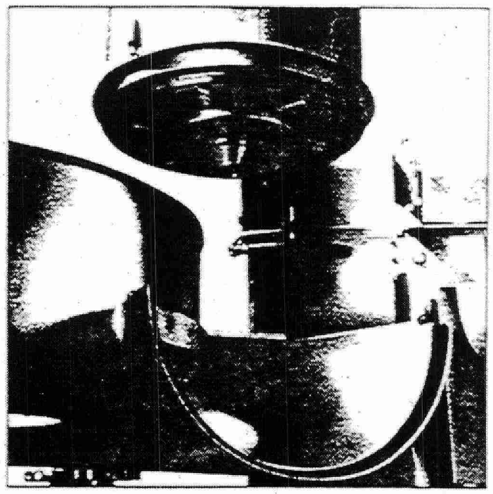
The screen unit is driven in intervals via hydraulic cylinders. The amount of intervals, their duration, as well as the opening time of the discharge valves are microprocessor-controlled. The CMF operates fully automatically and since the life time of the screen is extended drastically, costs for personnel and spares are considerably reduced.

*) FRG patent 34 30 992


Underwater pelletizer UWG


Three-roll smoothing unit


Water-ring pelletizer WRG in combination with screen changer SW


Water-ring pelletizer WRG

Three-roll smoothing unit

The three-roll smoothing unit is designed for the manufacture of thermoformable, embossed, laminated and multi-layered sheets and flat films.

The system consists of 3 stacked steel rolls arranged at an angle of 30°. Their heating/cooling is effected in a closed circuit by means of water or thermal oil.

The rolls are double-walled with spiral-shaped passages and provided with a hard chromium plated and polished surface.

The centre roll is fixed while the top and bottom rolls are pneumatically adjustable at the appropriate pretension. The precise adjustment of the roll gap — which is reproducible — is effected via adjusting wedges.

The rolls are separately driven by means of directly coupled D.C. motors of special design ensuring their absolutely uniform rotation.

For dismantling and adjusting the die, the smoothing unit is displaceable on guide rails.

Water-ring pelletizer *) - WRG

This pelletizer is particularly suitable for LDPE, HDPE, PP, PS, ABS, PC, EPDM etc. at throughputs from 100 to 6000 kg/h.

The plastic melt is cut »hot and dry« immediately after it emerges from the bores arranged in a circle in the horizontal die plate. The pellets are collected by a vertically flowing water film, intensively cooled and transported to a pellet dryer.

The WRG features low maintenance requirements and easy operation. Due to the vertical outflow of the plastic melt, starting can be effected without difficulties and completely independently from the cooling-water circuit.

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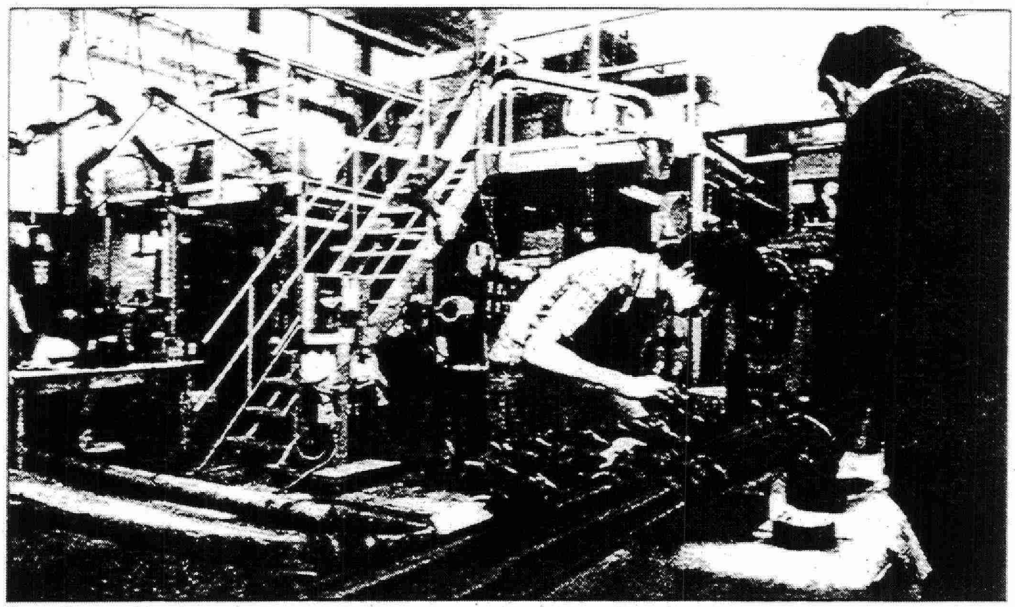
*) FRG patent 28 25 288
FRG patent 28 25 639
FRG patent 31 16 153
FRG patent 31 16 117

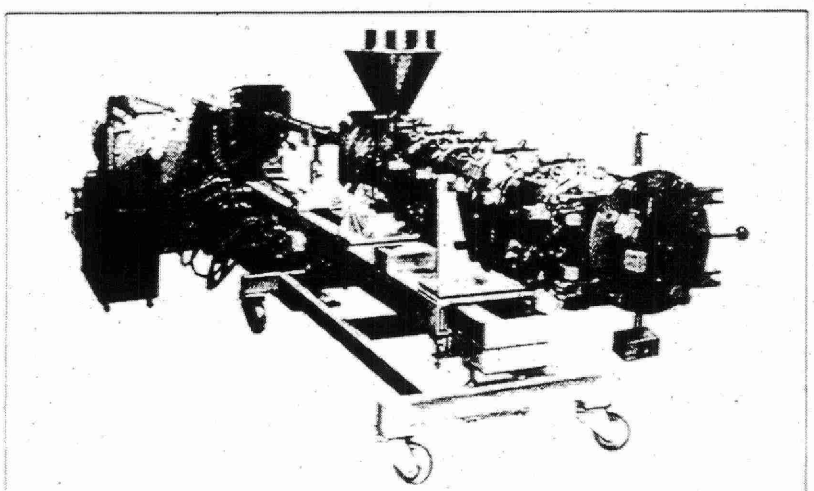
Underwater pelletizer - UWG

This device is suitable for the pelletizing of LDPE, HDPE, PP, PS and for throughputs from 500 to 25000 kg/h.

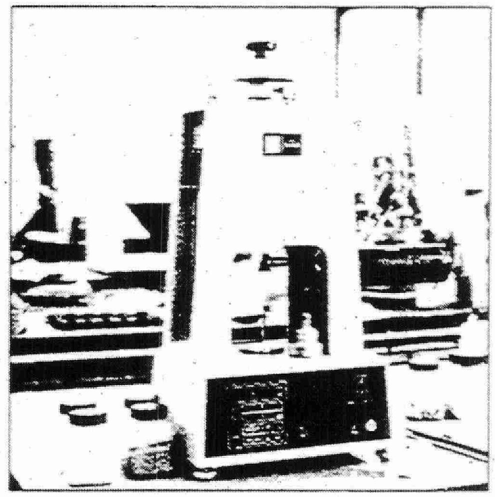
The plastic melt is cut under water immediately after it emerges from the bores arranged in a circle on the die plate. The pellets are simultaneously cooled and conveyed by the water. Operation and maintenance are quick and easy, knives can be changed without having to displace the pelletizer from the extruder. Setting of the knives is accurate and reproducible.



Berstorff process laboratory



ZE with extentable barrel



Material test

Process Laboratory

In our main plant in Hanover and in Charlotte/N.C., USA, Berstorff has established modern process laboratories where new processes and machines are tested under practice-oriented conditions. With regard to optimization of construction and processing features, all customers and interested parties are given the possibility to use these facilities for tests with their own materials.

The Berstorff process laboratories are fully equipped with laboratory and production machines. Twin-screw extruders, with 25, 40, 60 and 90 mm screw diameter in standard and two-stage design are available. These extruders can be fed either by means of a forced-feed device or by one or several dosing devices depending on the required process. Screw length and assembly are variable due to the building-block system. The material is discharged through melt filter units, profile dies or various pelletizing systems (KLG, WRG, UWG etc.).

Appropriate ex-proof precautions, storage of monomers in air-conditioned rooms, and air exhaust devices allow special tests such as monomer degassing and polymerisation; studies of chemical reaction processes can also be carried out.

The evaluation and the quality control of the extruded products with modern equipment are carried out in an adjacent Test Laboratory. During the tests, all data obtained is acquired and protocoled. The computerized information is subsequently statistically evaluated and graphically displayed. These units, conforming to the latest technical standard, enable us to carry out extensive tests, development and research work, beneficial to the future generation of extruders.

Technical data

Type	Screw-diameter	Channel depth	Screw length max.	Driving power max.	Screw speed max.	Torque	Axial load	Installed barrel heating power 28 D	Installed barrel heating power per barrel section
	mm	mm	L : D	kW	RPM	Nm	kN	kW	kW
ZE 25	25	4	48	10.5	550	2 × 90	15	5.5	1.1
ZE 40	40	4	48	40	500	2 × 400	122	12	2.4
ZE 40 A	43	6.5	48	40	500	2 × 400	122	12	2.4
ZE 60	60	6	48	150	500	2 × 1450	345	28.5	5.7
ZE 60 A	64	9.5	48	150	500	2 × 1450	345	28.5	5.7
ZE 75	75	7.5	48	230	400	2 × 2750	485	50	10
ZE 75 A	80	12.5	48	230	400	2 × 2750	485	50	10
ZE 90	90	9	48	350	350	2 × 4800	633	71	14.2
ZE 90 A	96	14.5	48	350	350	2 × 4800	633	71	14.2
ZE 130	130	13	48	850	300	2 × 13500	1420	135	27
ZE 130 A	140	22.5	48	850	300	2 × 13500	1420	135	27
ZE 180	180	18	40	1700	300	2 × 27000	2700	290	58
ZE 180 A	192	30	40	1700	300	2 × 27000	2700	290	58
ZE 230	230	23	39	3900	250	2 × 75000	4050	340	42.5
ZE 230 A	244	37	39	3900	250	2 × 75000	4050	340	42.5

Max. throughputs*) for certain processes (indicated in kg/h)

Processes	ZE 25	ZE 40 ZE 40 A	ZE 60 ZE 60 A	ZE 75 ZE 75 A	ZE 90 ZE 90 A	ZE 130 ZE 130 A	ZE 180 ZE 180 A	ZE 230 ZE 230 A
Compounding, stabilizing, coloring of HDPE, PP (powder)	50	160	500	850	1400	3500	8000	16000
Filling, compounding of 40 % talc in PP powder	45	160	500	850	1400	3500	8000	–
Reinforcing, compounding of 33 % GF in PA 6.6	40	150	450	730	1200	3000	–	–
Production of masterbatch in HDPE, LDPE, PP, PS, PA, ABS	35	120	390	730	1100	2700	–	–
Degassing of PS, SAN, PMMA pellets, and/or beads and/or powder of 0.5 % < 0.05 %	40	110	340	600	1400	2500	–	–
Recycling and degassing of LDPE, HDPE, PS, ABS (agglomerat)	–	150	500	850	1400	3500	–	–

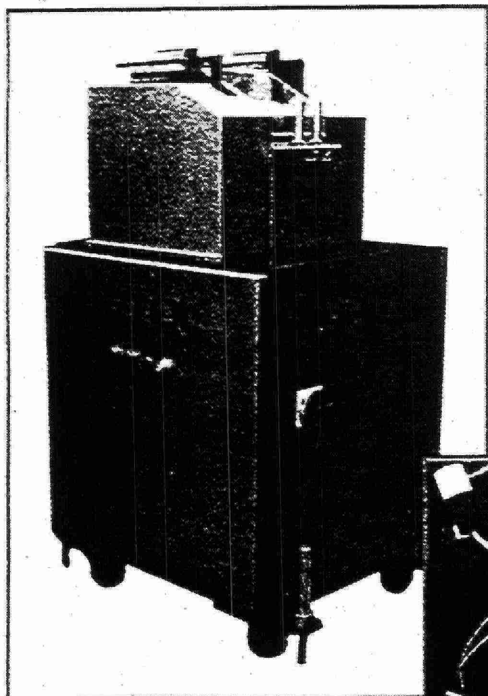
*) **The indicated throughputs depend** on the process, on the materials and on the formulas
Throughputs for other processes or products can be indicated on request or determined by tests in the laboratory of our research and development centre

Appendix B

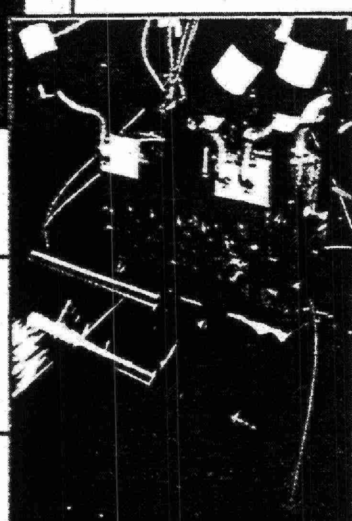
Extruder Manufacturers Information : Betol Machinery Ltd.

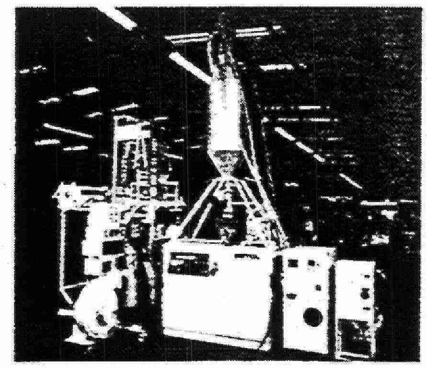
(6 pages)

Laboratory Extrusion Systems

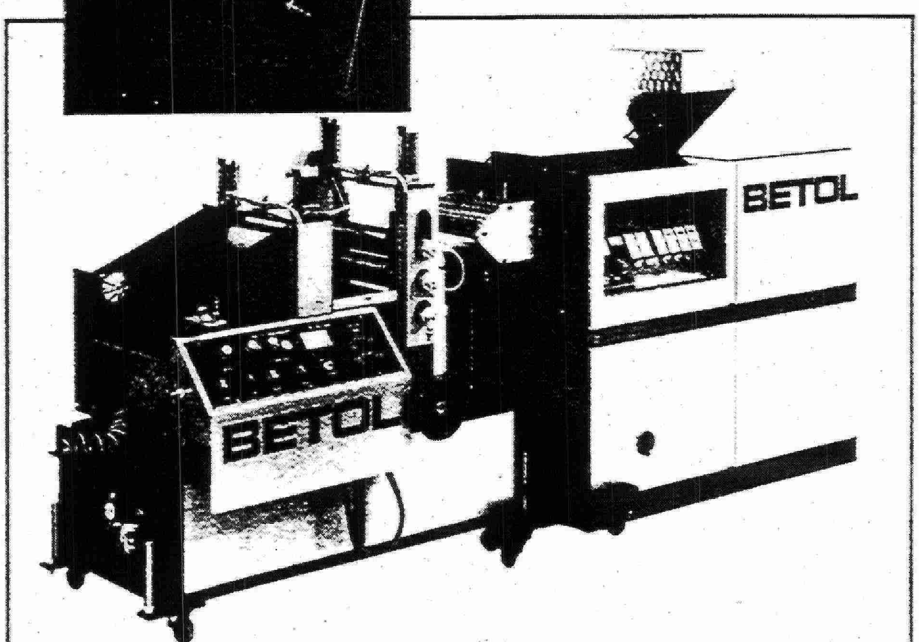


A range of high quality modular laboratory extrusion equipment for research, development and quality control, Betol's versatile equipment can be used for most extrusion processes including;





- compounding
- tubing
- rods
- profiles
- strip
- sheet
- cast-film
- blown film
- wire
- fibre optics
- monofilament



BETOL

Laboratory Extrusion Systems

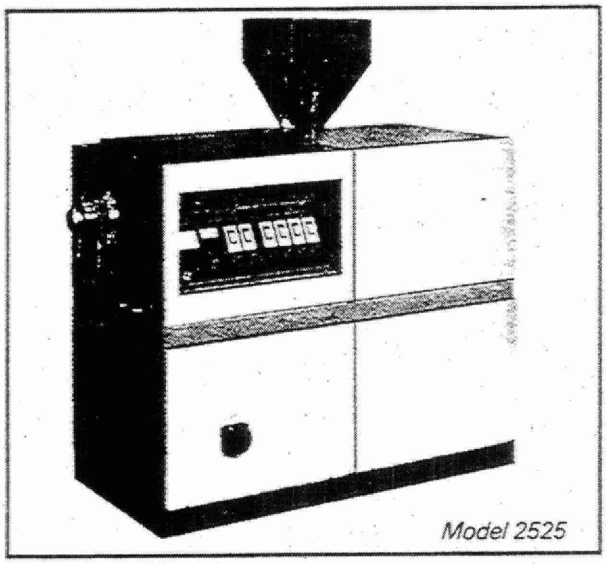
Betol is a World Leader in extrusion equipment for research, development and quality control with customers in over 80 countries worldwide.

Laboratory scale equipment is available for most extrusion processes including tube, profile, blown film, cast film, tape, sheet, wire/fibre optic sheathing, compounding and monofilament production.

All Betol's laboratory extrusion equipment is CAD designed and manufactured at a custom built factory in Luton, England, where all machined components, including extruder screws and barrels are made in-house on CNC machinery to ensure that a high degree of accuracy and consistency of quality is maintained. Bought in proprietary parts are selected for their reliability and performance characteristics. Mechanical and electrical assembly is carried out by trained, qualified engineers and every piece of equipment is fully tested prior to despatch.

Betol's laboratory extrusion equipment is modular in concept in order to allow several downstream processes to be used with the same extruder. This flexibility allows the expansion of the laboratory facility at a later date to include different or more elaborate processes in the most cost effective manner.

Equipment can be selected from a standard range or can be tailor made to suit special requirements, materials or applications. Betol's own microcomputer control and data aquisition systems are available for logging of process data and results, as is an extensive range of instrumentation.



Model 2525

SINGLE SCREW EXTRUDERS

Betol's precision engineered single screw laboratory extruders are available in screw diameters from 14mm to 38mm. Larger extruders up to 75mm can be selected from Betol's series 90 range.

Standard laboratory extruders have nitrided barrels and screws but special materials of construction including wear resistant and corrosion resistant alloys are available depending on requirements. Integral control panels are standard, reducing floor space and facilitating manoeuvrability.

Instrumentation can be selected from a wide range of options including melt temperature and pressure measurement, PID temperature control, screw torque measurement and full microcomputer control/data aquisition facilities. Materials handling equipment such as hopper loaders and driers can also be supplied.

Single Screw Laboratory Extruders Technical Data

Model Number	Nominal Screw Diameter	L/D Ratio	Screw Cooling	Main Drive Motor (KW)	Barrel Heating (per zone) (KW)	Barrel Zones	Die/Adaptor Zones
1420	14mm	20:1	—	0.36	0.4	3	1
1820J*	18mm	20:1	—	1.5	0.5	3	1
1825J*	18mm	25:1	—	1.5	0.5	3	1
1825	18mm	25:1	—	1.5	0.5	3	2
2520J*	25mm	20:1	√	1.5	0.65	3	1
2525J*	25mm	25:1	√	1.5	0.65	3	1
2525	25mm	25:1	√	3.0	0.65	4	2
3225J*	32mm	25:1	√	7.5	1.0	4	2
BC32	32mm	24:1	√	7.5	1.0	4	2
BC38	38mm	24:1	√	10.0	1.5	4	2

* J denotes adjustable height. Alternative L/D ratios are available to special order.

Laboratory Extrusion Systems

TWIN SCREW EXTRUDERS

Betol BTS co-rotating twin screw extruders are specially designed for compounding thermoplastics and thermoset systems. Three models are available, the BTS 30 machine has been developed for detailed analytical compounding analysis with the BTS 40 and 40L machines used for process analysis. The unique design features of the BTS range make them particularly suited to compounding polymer systems incorporating high filler loadings, heat sensitive and shear sensitive additives. All machines feature 4D interchangeable and reversible barrel modules allowing a wide range of configurations. Screws are available in short modular sections allowing the screw geometry to be infinitely adjusted to suit particular applications.

Barrel heating is rated to 500 degrees centigrade and each section is cored for liquid cooling. Temperature control is by three term PID controllers. The unique closely intermeshing screw design ensures efficient positive displacement and uniform output allowing blown film, sheet, cast film and tubes/profiles to be produced without the aid of a gear pump or other pressure building device.

Model BTS 40

Twin Screw Laboratory Extruders Technical Data

Model Number	Nominal Screw Diameter	Standard L/D Ratio*	Main Drive Motor (KW)	Maximum Screw Speed (rpm)	Barrel Module Length	Die Zones
BTS 30	30mm	21:1	5.5	200	4D	2
BTS 40	40mm	21:1	7.5	200	4D	2
BTS 40L	40mm	21:1	14	400	4D	2

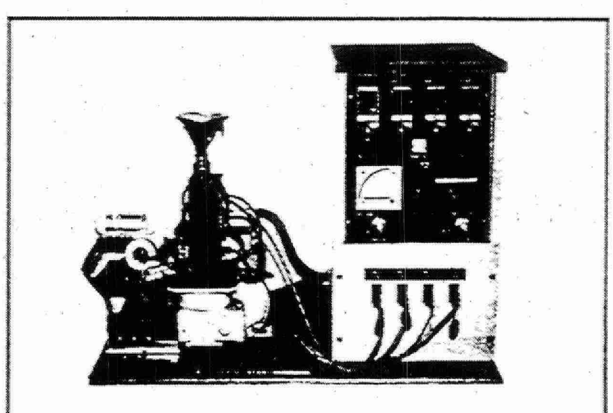
*L/D ratios from 17:1 to 37:1 are available in 4D increments.

MICROTRUDERS

Designed specially for research applications where only small quantities of polymer are available, the 6mm screw diameter microtruder allows film, thin sheet and rod samples to be produced from just a few grammes of powder, enabling comparative mechanical, physical and chemical tests between different formulations to be made.

The microtruder is available in two basic formats. The cast film system utilises a 50mm wide strip die and a 25mm diameter chill roll to produce films up to 1mm thick, while the pelletising system has a rod die, bath and dual purpose haul-off/pelletiser to enable rods and small pellets to be produced.

The extruder, common to both systems, has a vertical 6mm diameter screw which is driven by a motor from the metering end, thereby avoiding screw breakage problems associated with very small extruders. A water cooled feed section, three barrel zones and one die zone with PID temperature control are fitted as standard. All controls are fitted in an integral cabinet mounted on the extruder base, which is designed for bench mounting. More than one extruder can be combined with a special miniature feed block to produce multi-layer films up to five layers.



Microtruder Cast Film System

Laboratory Extrusion Systems

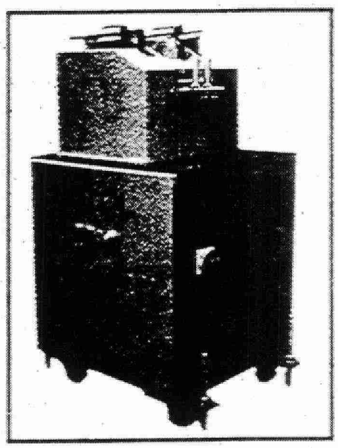
DOWNSTREAM EQUIPMENT

Compounding

Dies
Strand dies, from 1 to 5 strands manufactured in a range of metals including Hastelloy are available for fitting to Betol single or twin screw extruders.

Water Baths
Compounding water baths are available in 1.2m modules up to 4.8m. Each is manufactured with an adjustable height stainless steel bath section and fitted with guide rollers for separation of strands during cooling. An air knife for drying the product is fitted as standard.

Pelletiser
Betol's model 1308 laboratory pelletiser utilises a gearbox to allow a varying ratio of feed roll speed to rotor speed, giving adjustable pellet length. Feed roll speed range can be specified to suit particular applications.



Model 1308
Laboratory Pelletiser

Sheet and Cast Film

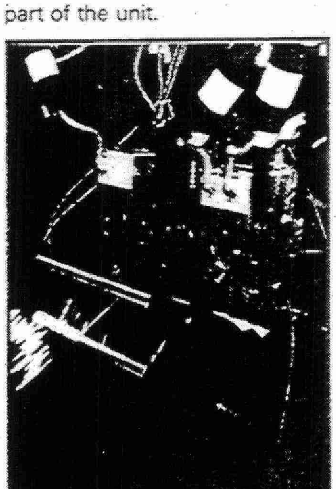
Co-extrusion Feedblocks
A range of co-extrusion feedblocks specially designed for laboratory applications can be used to produce sheet and cast film in up to seven layers and four different materials. Standard feedblocks are manufactured from tool steel and chrome plated with nickel plating or special alloys being used for applications where corrosion resistance is paramount. All feedblocks incorporate special viscosity compensators to allow optimisation of the layer structure with materials of differing viscosity.

Sheet and Cast Film Dies
Sheet and cast film dies are manufactured from tool steel with a coat-hanger internal design. All internal surfaces are highly polished and streamlined and restrictor bars can be fitted to control melt flow. Rigid lip sheet dies are available from 75mm wide, with flexible lip dies for sheet and cast film available from 100mm wide.

For less demanding applications and narrow widths, non adjustable tape dies can be supplied.

Three Roll Calendering Stacks
Betol's model 1013 three roll stack consists of three polished chrome plated rolls arranged one above the other. Each roll is fitted with rotary unions to allow circulation of heating or cooling fluid. The centre roll is fixed but the top and bottom roll can be adjusted by pneumatic cylinders to a set gap. The roll width range is from 150 to 500mm while the roll diameter depending upon width will be in the range 100mm to 300mm. A pair of 100mm diameter rubber covered pneumatically operated haul off rolls are positioned after the three roll stack.

Cast Film, Coating and Laminating Units
The multi-purpose 1215 film casting unit can be used for simple casting of film or by fitting optional extras, for coating, laminating or producing embossed film. The unit comprises a 200mm diameter hard chrome casting roll cored for fluid circulation, available in widths from 150 to 500mm with a set of pull rolls, all mounted on a common base and driven by a 1.5 KW DC motor. Unwind stands can be supplied as options for coating and/or laminating of fabrics, paper, plastic film or aluminium foil and either a centre driven or surface winder can be fitted as an integral part of the unit.



Laboratory Cast Film
Die and Chill Roll

A friction driven centre core winder can be fitted after the haul off rolls or a pneumatically operated guillotine can be substituted for cutting samples to length.

Tube, Rod and Profile

Tube, Rod and Profile Dies
Normally manufactured in tool steel but supplied in stainless steel, Hastelloy or other special metals if required. All Betol's tube, rod and profile dies have streamlined flow paths and are fitted to the extruder by quick release 'C' clamps for ease of removal and cleaning. Co-extrusion dies for multi-layer tubes or dual hardness profiles are also available.

Water Cooling Baths and Calibration Units
Standard model 119 baths are available in 1.2m long modules from 2.4m upto 9.6m long depending upon requirements. All are adjustable in three planes and the bath sections are in stainless steel. Castors and jacking screws are fitted for manoeuvrability.

One or more heated sections can be provided for controlled cooling of difficult materials. A venturi vacuum calibration unit can be fitted to all baths for sizing tubes and tubular profiles and a simple plate calibration tray or small dry vacuum calibration table and pump can be fitted if required for profiles.

Air knives for drying the product are fitted as standard to all baths.

Haul-Off Units
A range of haul-offs including nip roll, capstan and caterpillar types are available All haul-offs are driven by DC motors with armature feedback as standard. Tacho feedback or digital speed control can be fitted for critical applications where accurate motor speed holding is required.

Integral control panels are fitted as standard and speed ranges and belt widths can be selected to suit most applications.

Cutters
A variety of Betol cutting systems are used where the extrudate is required to be cut to length in line. For most laboratory applications, where length tolerance is not critical, a pneumatic guillotine unit can be fitted to the haul-off to enable variable length samples to be cut. Where more demanding tolerances or higher cutting rates are needed a separate rotary cutter or travelling saw can be supplied from Betol's extensive range of production downstream equipment.

Laboratory Extrusion Systems

Blown Film

Film Dies and Air Rings

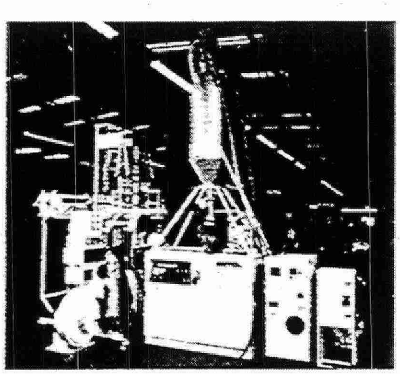
Two types of blown film die can be specified depending upon applications. The simplest model which is ideal for laboratory use since it is readily disassembled for cleaning is underfed with the internal die pin supported by a spider arrangement. All internal surfaces are streamlined and highly polished to assist melt flow and for greater flexibility in temperature control the die body and die land area are separately controlled. This die model is available in diameters ranging from 15mm to 100mm.

The second model is manufactured with a spiral mandrel having two or more starts depending upon requirements. In addition to mono dies, co-extrusion dies for up to three layers in three different materials can be supplied. Spiral mandrel dies can be supplied with a variable speed oscillating mechanism capable of rotating the die through 190 degrees to ensure uniform appearance of film rolls. With the oscillating mechanism the die is mounted on a support trolley and is available in diameters ranging from 50 to 150mm

Both models of die are available with a fully adjustable dual flow laboratory air cooling ring with fan.

Model 0250 Film Tower

Constructed with two heavy support arms this tower is ideal for laboratory use because of its easy mobility and flexibility in nip roll frame height which can be adjusted in any position between 1550mm and 2590mm by rotating a handwheel The nip rolls, one hard chromed and the other rubber covered, are pneumatically operated with adjustable air pressure and driven by a 0.75 KW DC thyristor controlled motor with an infinitely variable speed between 1 and 75 metres minute.



Laboratory Blown Film Line

As optional extras a tacho feedback system can be fitted to the DC drive motor to ensure exceptionally consistant speeds and the nip rolls can be water cooled. The fully adjustable collapsing boards can be slatted or plastic faced or fitted with rollers depending upon requirements. Controls and instrumentation are mounted in a panel attached to the side of the tower which is designed to accommodate layflat widths up to 420mm.

Betol's laboratory film towers are fitted with an integral winder and two types are available depending upon requirements.

The simplest unit is a 2-station centre core winder with dancer tension control system.

Alternatively a single station surface winder with a 250mm diameter rubber covered roll, inclined rack and tension control can be supplied. Controls for both types of winders are mounted alongside the film tower controls.

Wire, Fibre Optics Sheathing

Cross-head Dies

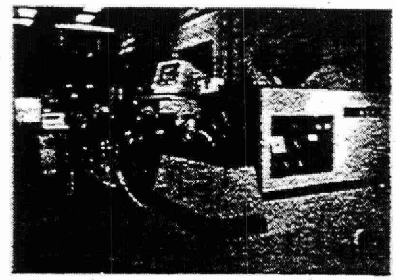
Small manual or cartridge type self centering tool steel cross-head dies are available. Special steels such as Hastelloy can be specified if required. Die bush and guide assemblies include those suitable for fine wire, fibre optic or other cores and options include vacuum pull down, water cooling or gel feed.

Pay-off and Unwind Units

A range of small pay-off units from simple rod brake types to low tension driven unwind units with reel cross traverse mechanism can be specified depending on application. Where accurate feed rate of the conductor or optic core is required, Betol's mini pay-off capstan which uses a grooved guide pulley and neoprene covered drive wheel can be fitted just before the die.

Water Cooling Baths

Betol manufactures specially designed Model 121 stainless steel spray cooling baths, fitted with a 300mm long telescopic front section, reservoir tank and re-circulating pump in either 2.4 or 4.8m lengths. The extrudate runs in a vee trough with water being applied by spray pipes. For some applications a venturi vacuum calibration unit can be fitted.



Laboratory Fibre Optic Sheathing Line

Capstan Haul-Offs

Betol laboratory wire and fibre optic sheathing lines normally utilise the model 912 capstan haul-off which has a 600mm diameter aluminium wheel driven by a DC motor with tacho feedback for accurate speed control. The capstan has provision for two complete wraps of the sheathed core which are held in position by a neoprene pressure belt.

Winders

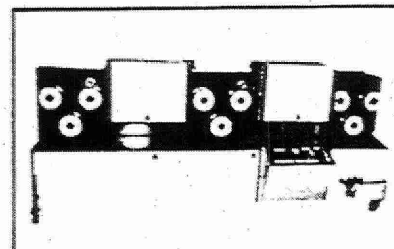
Either a cantilever type winder for heavier reels or a traversing winder for lighter products including fibre optics can be supplied depending on requirements. Tension control is normally provided by a separate dancer arm system.

Monofilament

Laboratory units with either two or three sets of godet rolls can be supplied depending on application.

Each set of godet rolls is independently driven by DC motors and speed ranges can be selected to provide desired draw down ratios.

Radiant heating stations with adjustable thermostats for temperatures up to 200 degrees centigrade are fitted. All controls are mounted in an integral control panel and the unit is mounted on castors.



Laboratory Godet Unit

Laboratory Extrusion Systems

Microcomputer Control Systems
Betol's own, highly developed, M700 series microcomputer systems can be used for data aquisition or if required full extrusion line control. All software is written in-house individually for each customer by Betol using the experience of our own test engineers to ensure that the system is as user friendly as possible and tailored to each customers needs.

Each system is based upon one of four M700 series microcomputers. The simplest system, Betol's model M712, controls temperature of the extruder barrel and die zones and provides monitoring and data aquisition facilities for up to eight process variables, for example screw speed, melt temperature, pressure and screw torque.

More extensive control and monitoring facilities are available on more advanced models up to Betol's M740 which can provide control of all elements of the extrusion line and monitor and produce histograms of a wide range of process variables including motor and heater power consumption and differential melt pressures and, with the appropriate measuring devices, product dimensional information.

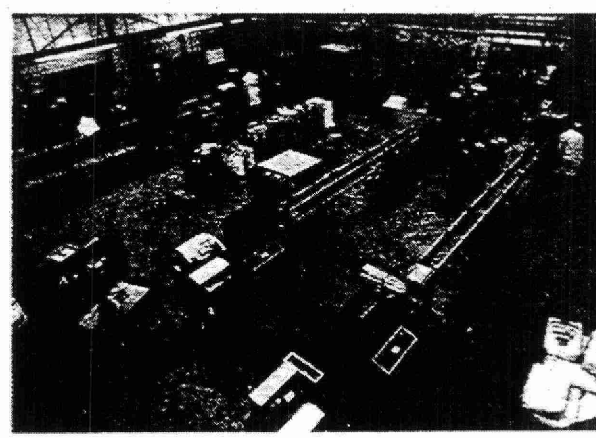
A vast range of options enable Betol's microcomputers to communicate via data links with either PC's or central systems.

Typical features of Betol's M700 microcomputer include:

- control of extruder temperature
- monitoring of conditions
- multiple storage of recipes
- production information and display
- histograms of selected process variables
- data links to existing computer systems
- restricted access facilities

Laboratory Facilities
Trials and demonstrations can be provided at Betol's own laboratory and test department facility at the Luton factory, where a range of equipment can be made available for evaluation of materials, processes or our equipment.

Customers are also welcome to visit to see Betol's facilities and to discuss particular projects.



Betol's Test Department

The Betol Product Guarantee — Your Insurance

Every extrusion line manufactured by Betol is assembled and fully tested under production conditions in our Luton factory and is delivered only when the customer is satisfied that output, quality and tolerances meet those specified at the time of order.

Because of continuing developments, Betol reserves the right to change their technical specifications without prior notice.

BETOL

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Appendix C
Interview Questions
(1 page)

Typical questions asked of companies interviewed as part of Task 4.

All companies requested anonymity.

What price do you pay for crumb rubber?

Could you use reclaimed rubber?

What sort of properties do you need for a reclaimed rubber?

What are your basic processing costs?

What volumes of reclaimed rubber do you currently require?

What are your future needs?

Do you plan to use reclaimed rubber in the near future?

What would you consider an appropriate size for a reclaiming facility?

What sort of operating hours should the facility be operated?

What do you know about reclaim/devulcanized materials?

Who sells reclaim in Ontario?

Where do you see the best opportunities for a devulcanized material?

What would you consider the market size for reclaimed material in Ontario?

Where is the cost/performance balance for a reclaimed material?

What price would you pay, per kg, for a reliable source of reclaimed scrap tire?

Appendix D

First Progress Report

(39 pages)

Appendix E

Second Progress Report

(94 pages)